

Progress on NOAA's hourly updating Rapid Refresh model/assimilation

Stan Benjamin -
NOAA Earth System Research Lab
Steve Weygandt

Other key colleagues at ESRL
Joe Olson Ming Hu
Tanya Smirnova Dezso Devenyi
John M. Brown Georg Grell
Bill Moninger Kevin Brundage
Bob Lipschutz

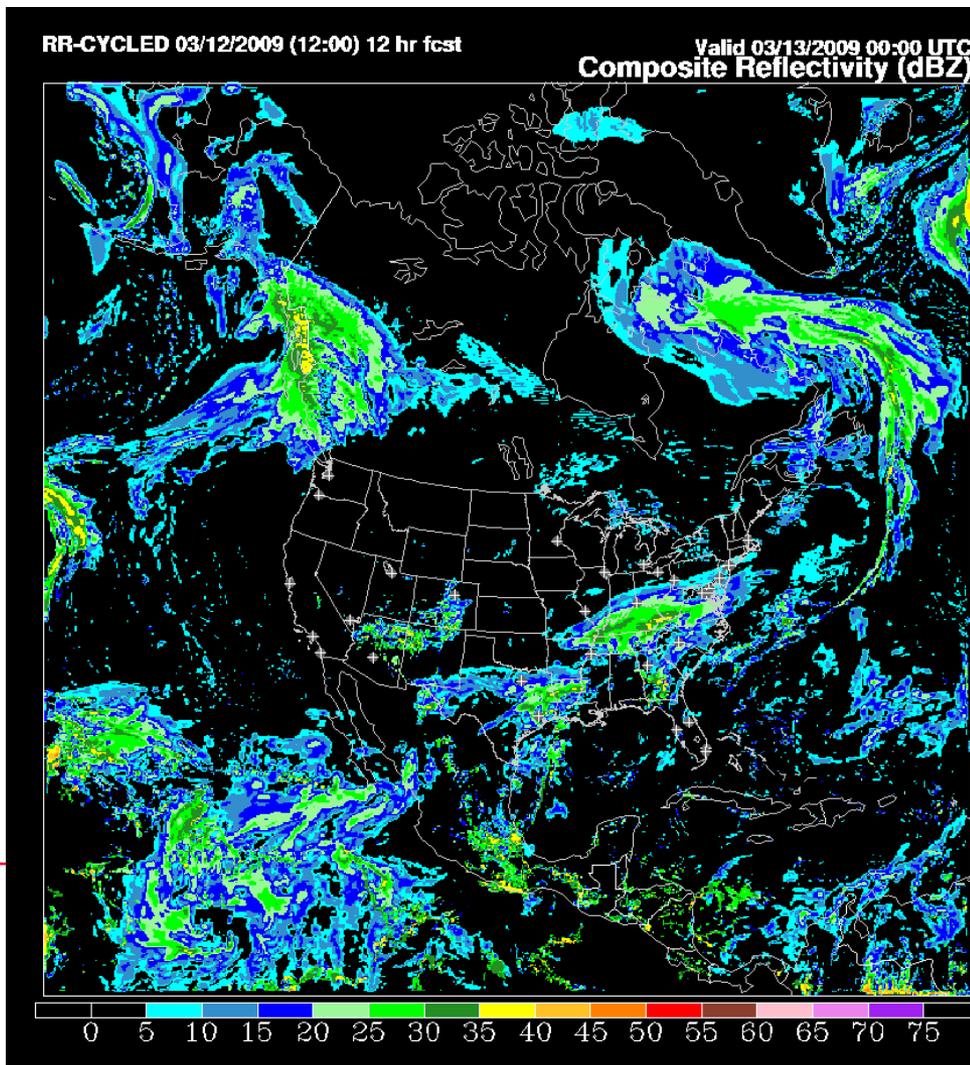
Thurs 12 March 2009

<http://rapidrefresh.noaa.gov>

<http://ruc.noaa.gov>

<http://ruc.noaa.gov/hrrr>

<http://fim.noaa.gov>



RUC and Rapid Refresh domains

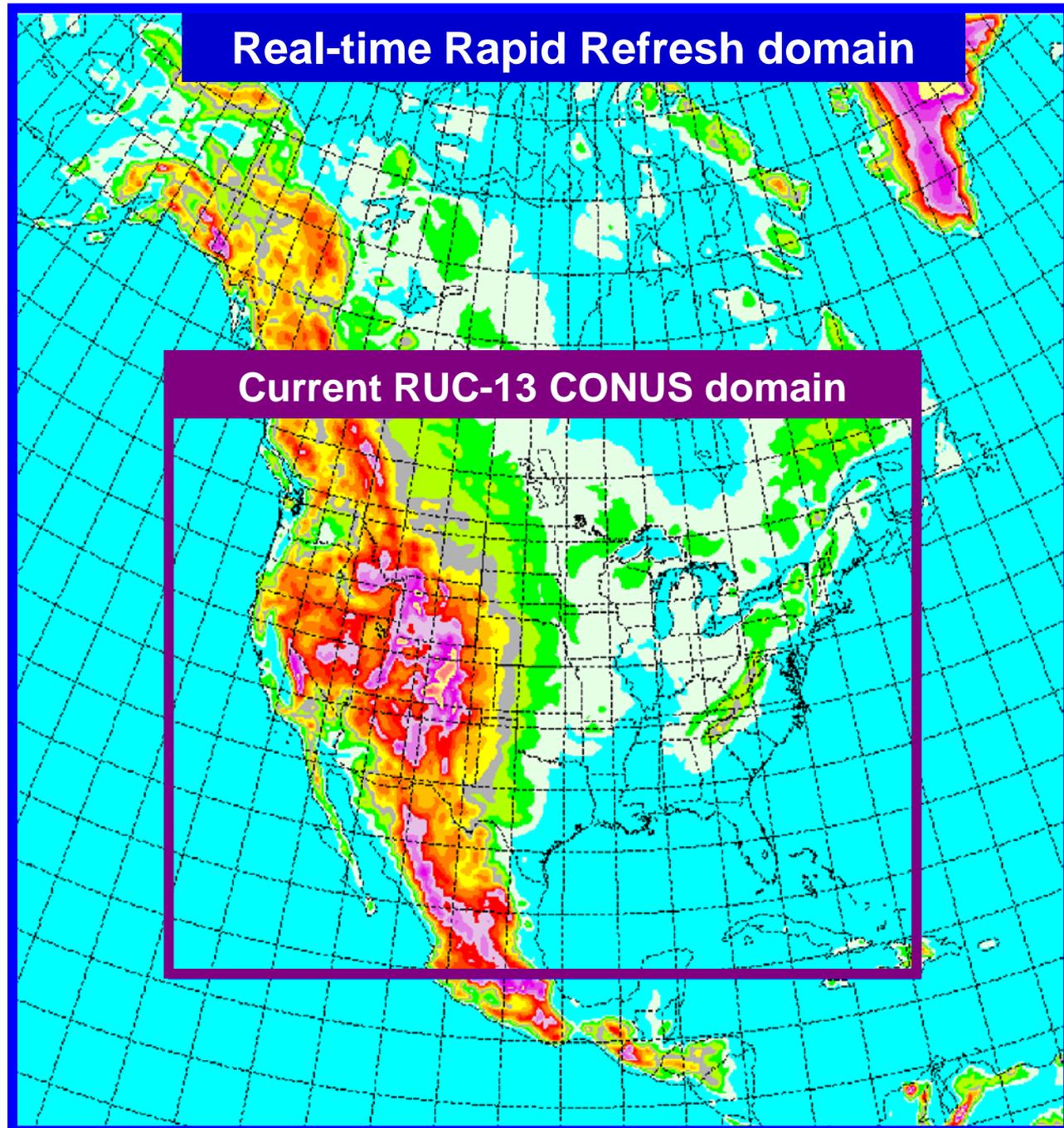
Rapid Refresh

NCEP implement:
Planned spr 2010

Features:

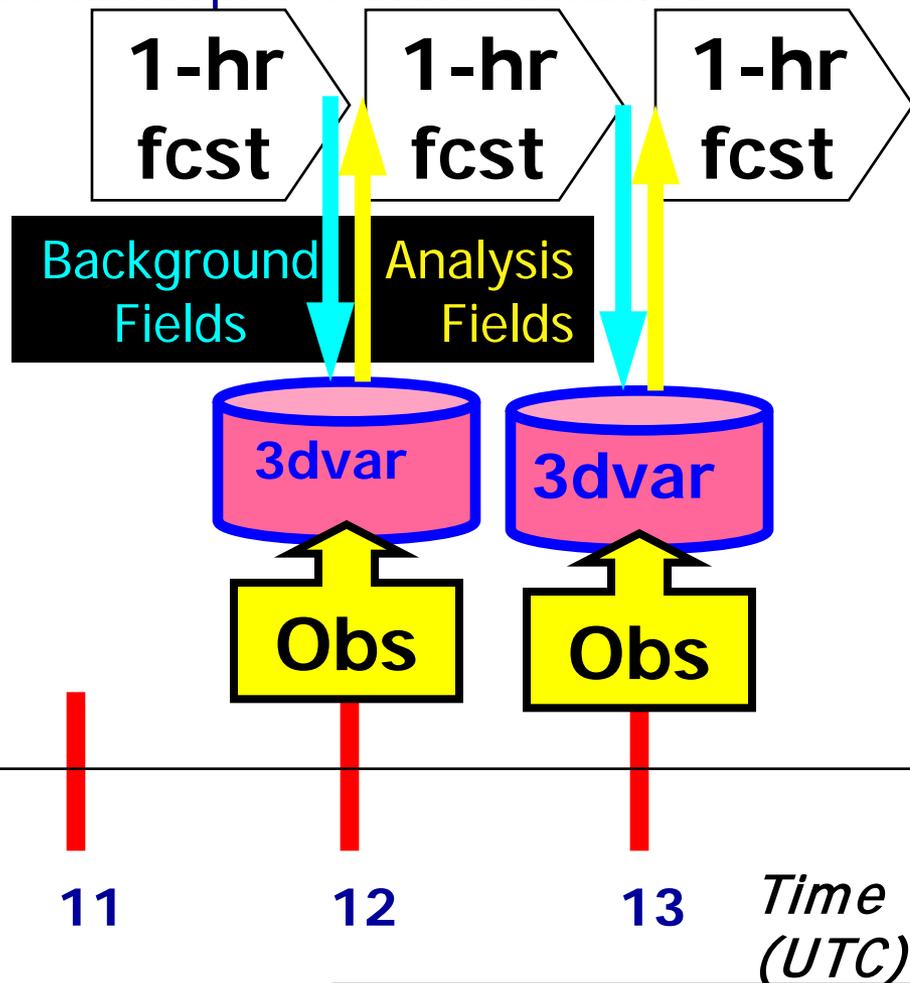
1-h cycling
Cloud analysis
Radar / lightning
assimilation

Current testing:
2 parallel cycles
at ESRL/GSD



RUC / Rapid Refresh Hourly Assimilation Cycle

Cycle hydrometeor, soil temp/moisture/snow plus atmosphere state variables

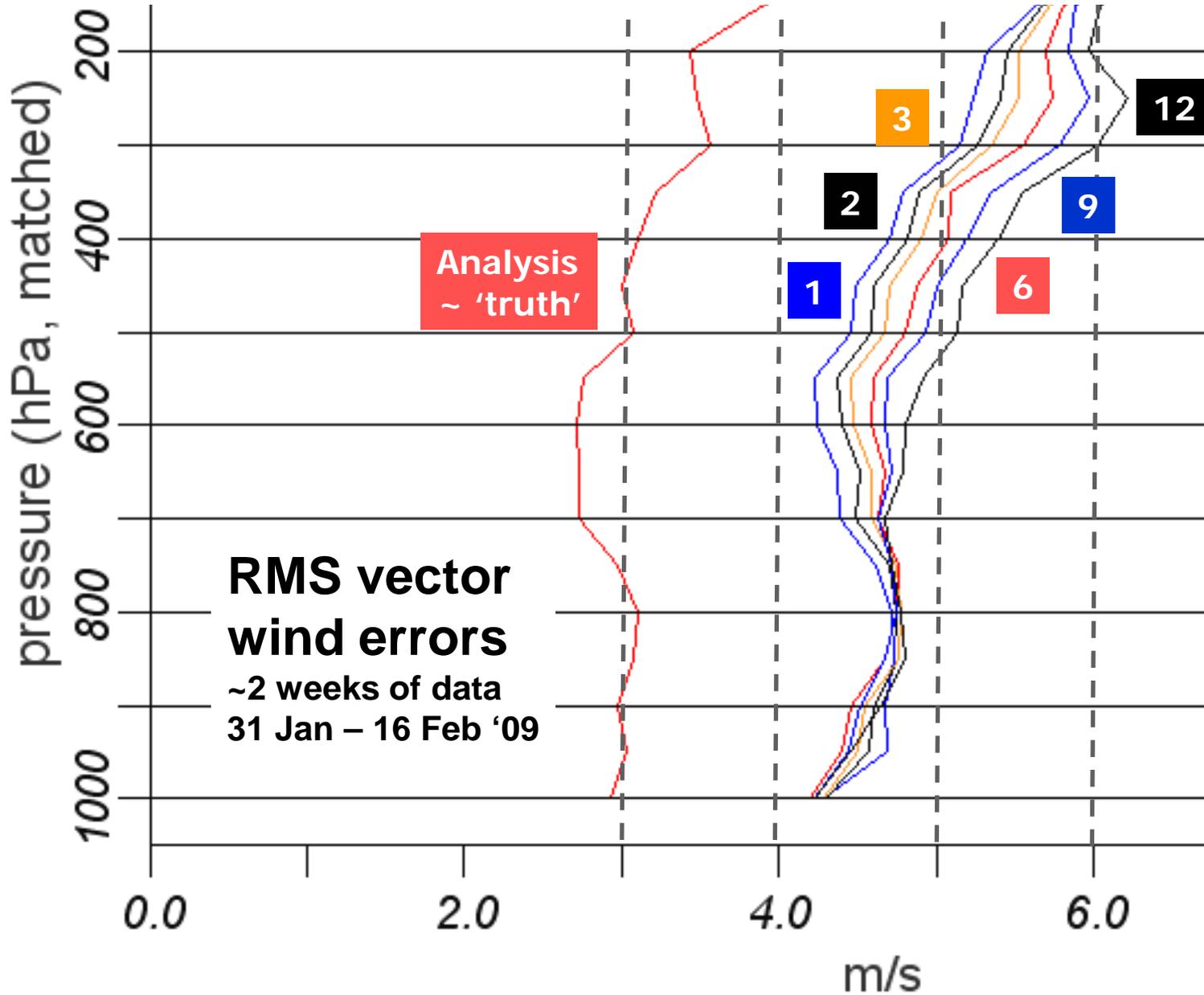


New for Rapid Refresh

Hourly obs in 2008 RUC

Data Type	~ Number
Rawinsonde (12h)	80
NOAA profilers	30
VAD winds	110-130
PBL – profiler/RASS	~25
Aircraft (V,temp)	1400-5000
→ TAMDAR (V,T,RH)	0 -1800
Surface/METAR	1800-2000
Buoy/ship	100- 200
GOES cloud winds	1000-2500
GOES cloud-top pres	10 km res
GPS precip water	~300
Mesonet (temp, Td)	~7000
→ Mesonet (wind)	~4500
METAR-cloud-vis-wx	~1600
→ Radar refl/lightning	1km
AMSU A/B radiances	
ASCAT winds (testing)	

Rapid Update Cycle (RUC)



**RUC/RR - one of NCEP operational models
1h update cycle - focus - aviation, severe
weather, situational awareness, energy**

<u>NCEP Component</u> – Description of Changes	Date
HiResWindow – NMM v2.2+ & ARW v3 upgraded to 4-5km on expanded domains and using WPS	11 Sep 07
NAM – NMM v2.2+ I,J,K version, unified NOAH LSM, Gravity Wave Drag, expanded domain	21 Mar 08
RUC - radar reflectivity assimilation (first radar refl assim at NCEP), TAMDAR assimilation, RRTM longwave radiation	17 Nov 08 16 Dec 08
NAM – NMM ~v3.0, using WPS and partial cycling, TAMDAR assimilation	16 Dec 08

Extract from NCEP 2009-2010 Plans

<u>NCEP Component</u>	<u>Description of Changes</u>
HiResWindow	Initialize with GSI & digital filter (DFI), use Doppler winds+reflectivity, increase resolution
NAM	Move to ESMF-based NEMS infrastructure and NMMB (essentially WRF-NMM on B-grid), include concurrent nests: 4 km CONUS & 6 km Alaska. GSI: new dynamic constraint, DFI, better QC, better use of and more aircraft, radar & satellite data, use GFS channel bias corrections
SREF	Stochastic physics, everything NEMS-based, extended bias correction, output downscaled using RTMA
VSREF	Experimental – produce full set of output variables, updated hourly using RUC/RR, NAM and SREF (eventually GFS + GEFS/NAEFS too)
RUC	Extend hourly forecasts to 18hr
Rapid Refresh	Replace RUC analysis & model with GSI and WRF-ARW, extend domain to cover Alaska

RUC to Rapid Refresh

- CONUS domain (13km)  • North American domain (13km)
- RUC model  • WRF model (RR version) (ARW dynamic core)
- RUC 3DVAR  • GSI (Gridpoint Statistical Interpolation) (incl. RR enhancements)

History of Rapid Refresh

- **2003-5 -**
 - Initial testing of “WRF-RUC” - WRFv1.* initialized with RUC grids
- **2006-07**
 - Introduction of updated RUC physics into WRF (Grell-Devenyi convection, RUC/Smirnova land-surface)
 - WRF ARW/NMM core comparison for Rapid Refresh - controlled experiments - 2 physics suites (NAM, RUC)
- **2007 - Initial cycling of RR with GSI and WRF**
- **2008 -**
 - reliable access to NCEP obs files for Rapid Refresh
 - introduction of GOES/METAR cloud analysis from RUC into RR
 - introduction of digital filter initialization to WRF
 - introduction of DFI-radar reflectivity assimilation for WRF-RR
- **2009**
 - Feb - sharper terrain, closer fit to surface observations
 - March (so far) - intro of cycling temp in 2nd snow layer

NCEP/GSD Agreement on Rapid Refresh - signed 12 September 2007

- **2009/10 – Initial Rapid Refresh – Phase 1**
 - Model - WRF-ARW, Rapid Refresh physics
 - Data assimilation – GSI with RR-developed enhancements
- **2012 – Ensemble Rapid Refresh – Phase 2**
 - 6 members, 3 each using ARW and NMM
 - Model (ARW, NMM) and GSI will use ESMF framework, not WRF framework
 - Model/assimilation systems from NOAA/ESRL and NCEP

RR version of WRF model

ARW core

Grell-Devenyi convection

*Components in
red match RUC*

MYJ (NCEP/NAM) surface layer,

turbulent vertical mixing above surface layer

NCAR-Thompson microphysics

RRTM longwave radiation

Goddard shortwave radiation

RUC Land-Surface Model (diversity from Noah LSM
in anticipation of ensemble RR by 2012)

Diabatic Digital Filter Initialization (DDFI) radar assim

*Result: RR physics behavior similar to RUC –
good for aviation applications and convective environment*

Main accomplishments toward RR

- **GSI adapted for GSD Linux computer with WRF-ARW background**
- **Addition of cloud-hydrometeor analysis to GSI**
- **DFI added to WRF (v3.0)**
 - RUC-like design, accumulation in wrf.F90 - usable for other dynamic cores. (initial application w/ ARW core)
- **Updated versions in WRFv3.0 of**
 - Grell-Devenyi scheme (option 5 for convection)
 - RUC-Smirnova scheme
- **WPS changes such that RUC native data (including hydrometeors and LSM fields) can be used easily by community WRF users**

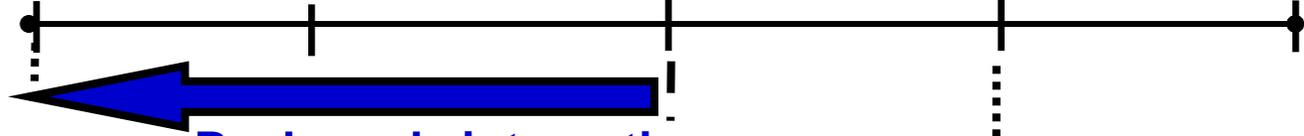
RR Status 10 Feb 2009

- Hourly experimental cycle continues to run with good reliability
- Still investigating periodic (~3 every days) model crash along southern boundary over high terrain of Colombia, S.A.
- New code in place to cycle LSM fields through model cold-start
- Realtime verification over Alaska using MET software:
plots: <http://rapidrefresh.noaa.gov/AKverify/>

Diabatic Digital Filter Initialization (DDFI), used in RUC

- Application into WRF - **completed for ARW, in WRFv3.0**

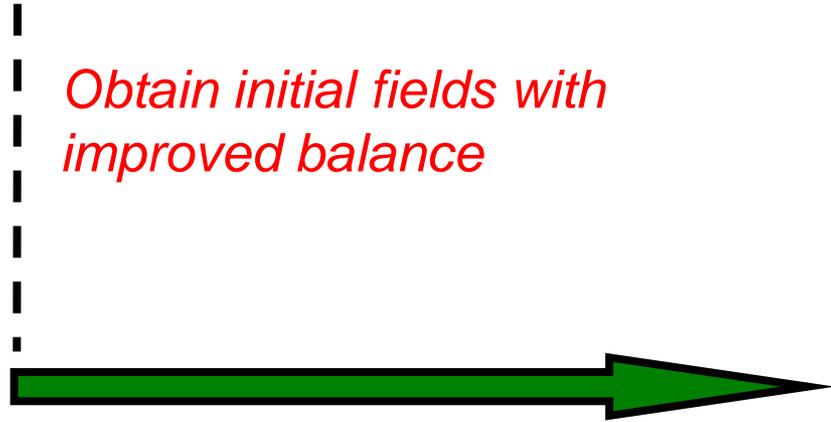
(Tanya Smirnova, Steven Peckham, Stan B., John Brown)



Backwards integration,
no physics



Forward integration,
full physics



*Obtain initial fields with
improved balance*

model forecast

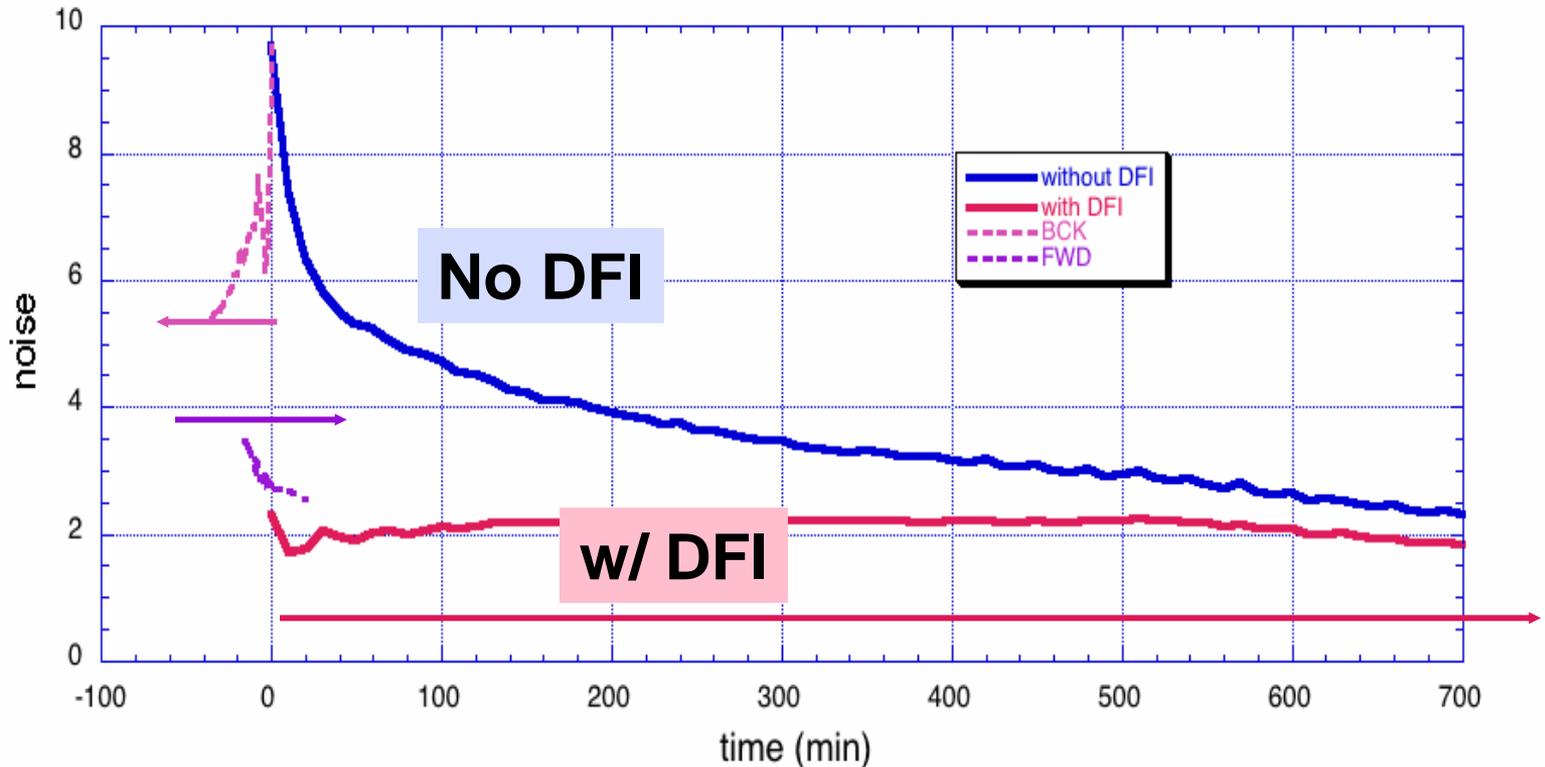
Function of DFI: Remove high-frequency oscillations (particularly, gravity waves) from the initial state for the forecast

⇒ creates smoother background for next analysis

Quieter forecasts in WRF using DFI

Noise = mean absolute sfc pressure tendency (hPa/h)

$$\left| \frac{\partial p_{sfc}}{\partial t} \right|$$



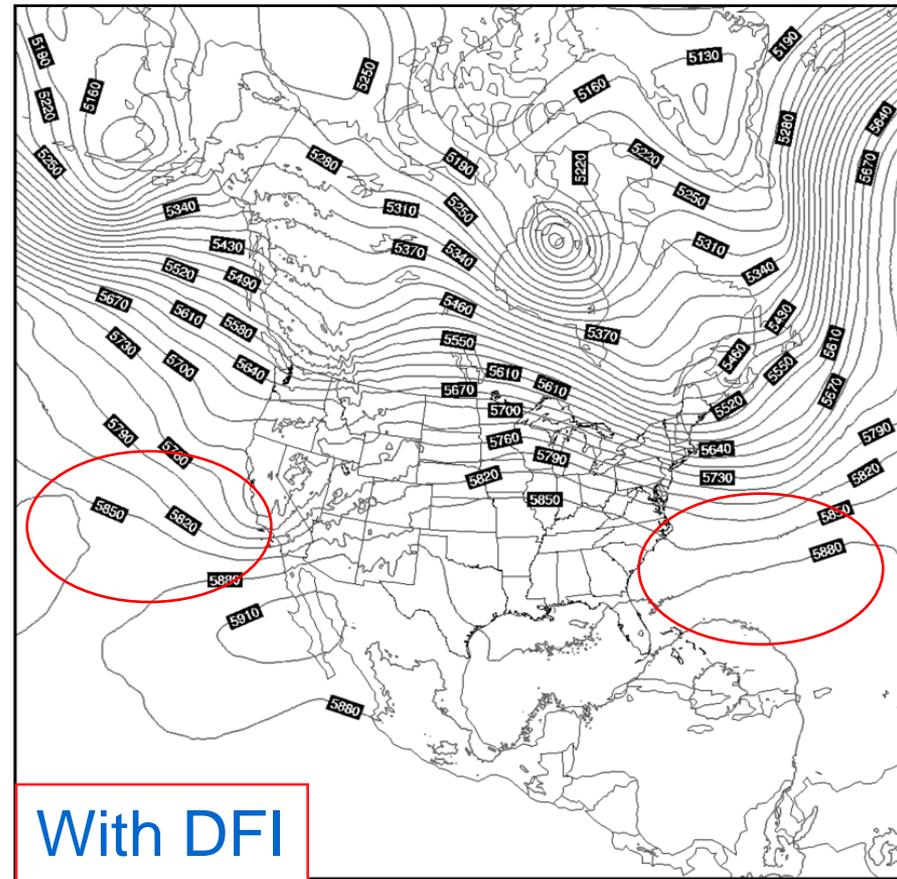
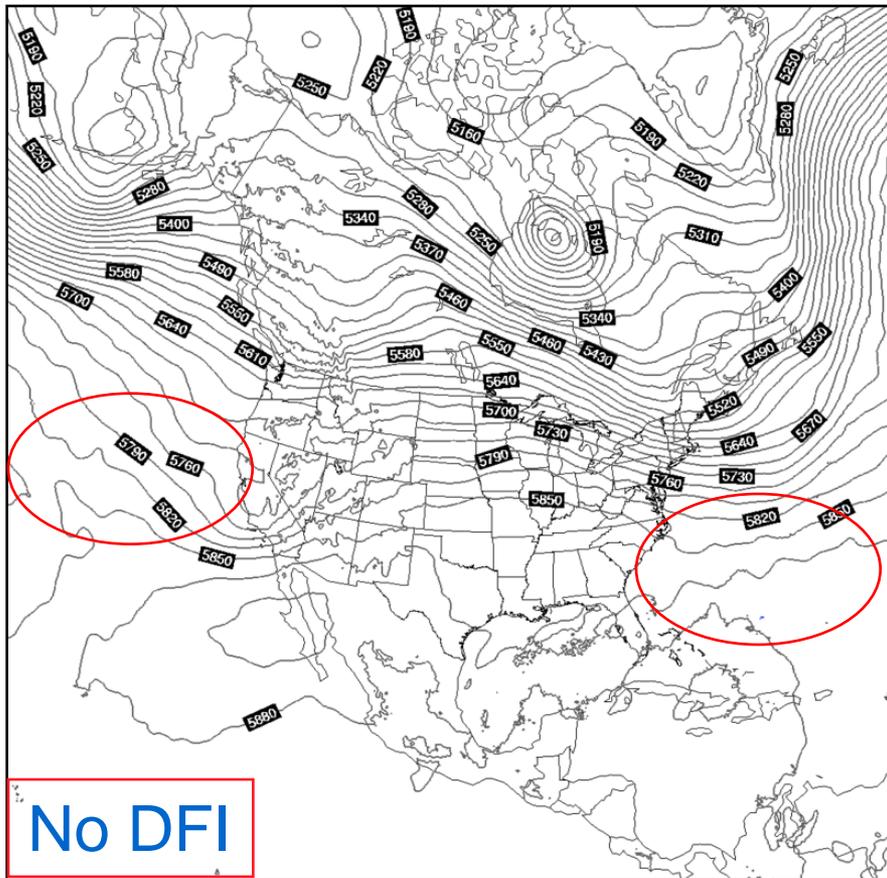
Using WRF-13km Rapid Refresh over N. American domain

Successful for reducing noise in 1h WRF fcst, as with RUC

500mb Height 3-h Fcst for 03Z 30 Oct 07

Rapid Refresh WRF

Away from terrain and convection, height contours are smoother with DFI



RR Data Assimilation

Application of GSI for RR (Gridpoint Statistical Interpolation)

- GSI - NCEP's unified community assimilation system
 - 3dvar, work toward 4dvar
- GSI adapted from global Spectral Statistical Interpolation (SSI) toward unified NCEP analysis
 - Used for operationally in GFS, NAM, RTMA
 - Primary development by NCEP/EMC and NASA/GMAO (via JCSDA), ESRL/GSD now collaborating on regional GSI
- Includes satellite radiance assimilation package
 - Not in current RUC, critical for large oceanic coverage in RR
- Work with EMC on RR application of GSI:
 - 1) Use of background from ARW w/ 5 hydrometeor types
 - 2) Cloud analysis (satellite, METAR, radar, LTG obs)
 - 3) Surface obs assimilation (PBL depth, coast-lines)
 - 4) Force convection from radar, lightning data in model DDFI

RR data assimilation (using GSI)

Hourly update cycle

- Use of observations (NCEP prepBUFR + satellite data)
- Satellite bias corrections (from NCEP)

Cloud analysis

- Uses METAR, satellite, radar data
- Updates cloud, hydrometeor, water vapor fields
- Diagnose latent heating from 3d radar reflectivity data

Radar reflectivity assimilation

- Apply latent heating in diabatic digital filter initialization

Surface observation assimilation -- ongoing

- Account for model vs. terrain height difference
- Apply surface observation innovations through PBL
- Select best background for coastal observations

RR data assimilation (using GSI)

Hourly update cycle

- Use of observations (NA prepBUFR + satellite data)
- Satellite bias corrections (from NCEP)

Cloud analysis

- Uses METAR, satellite, radar data
- Updates cloud, hydrometeor, water vapor fields
- Diagnose latent heating from radar data

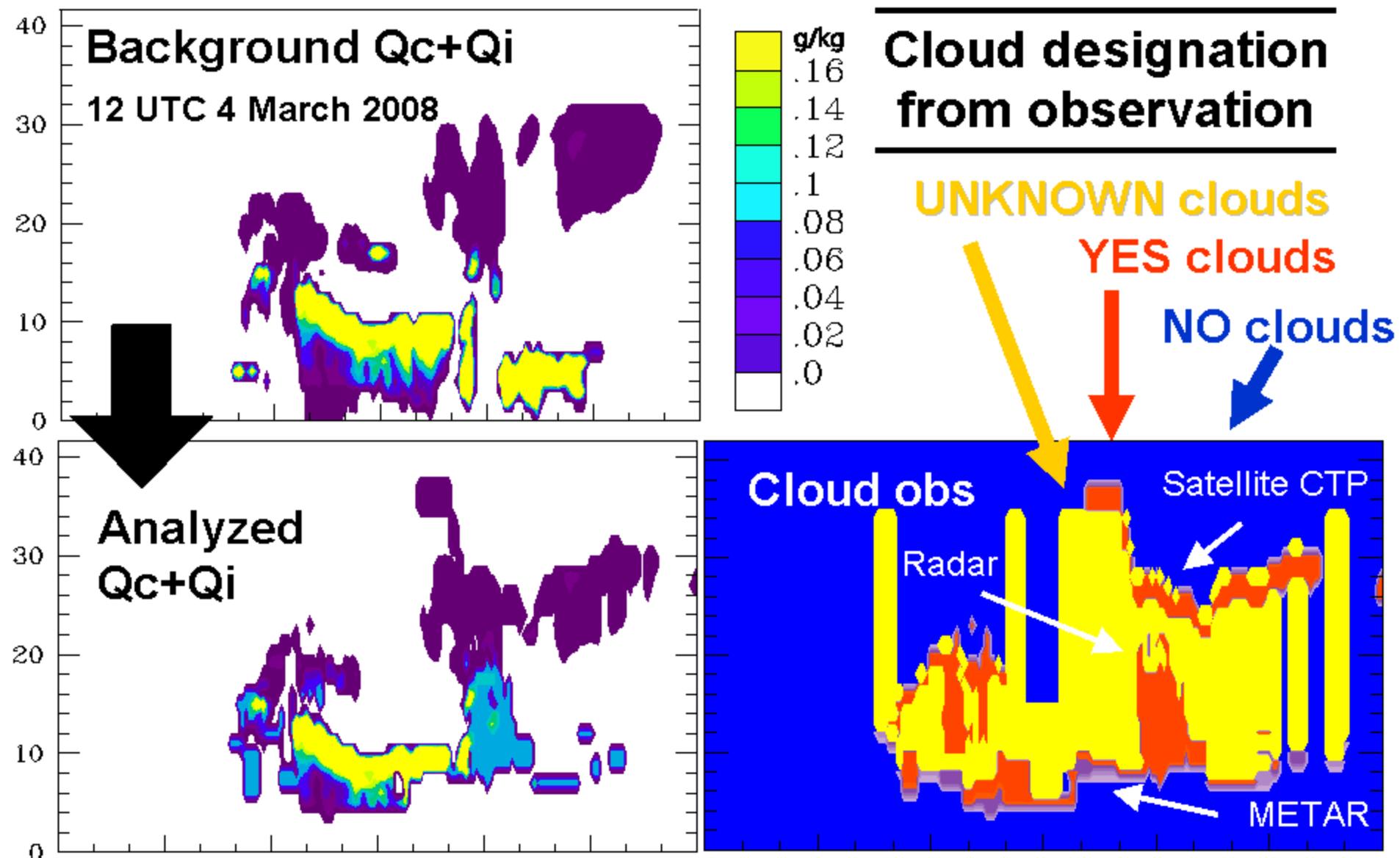
Radar reflectivity assimilation

- Apply latent heating in diabatic digital filter initialization

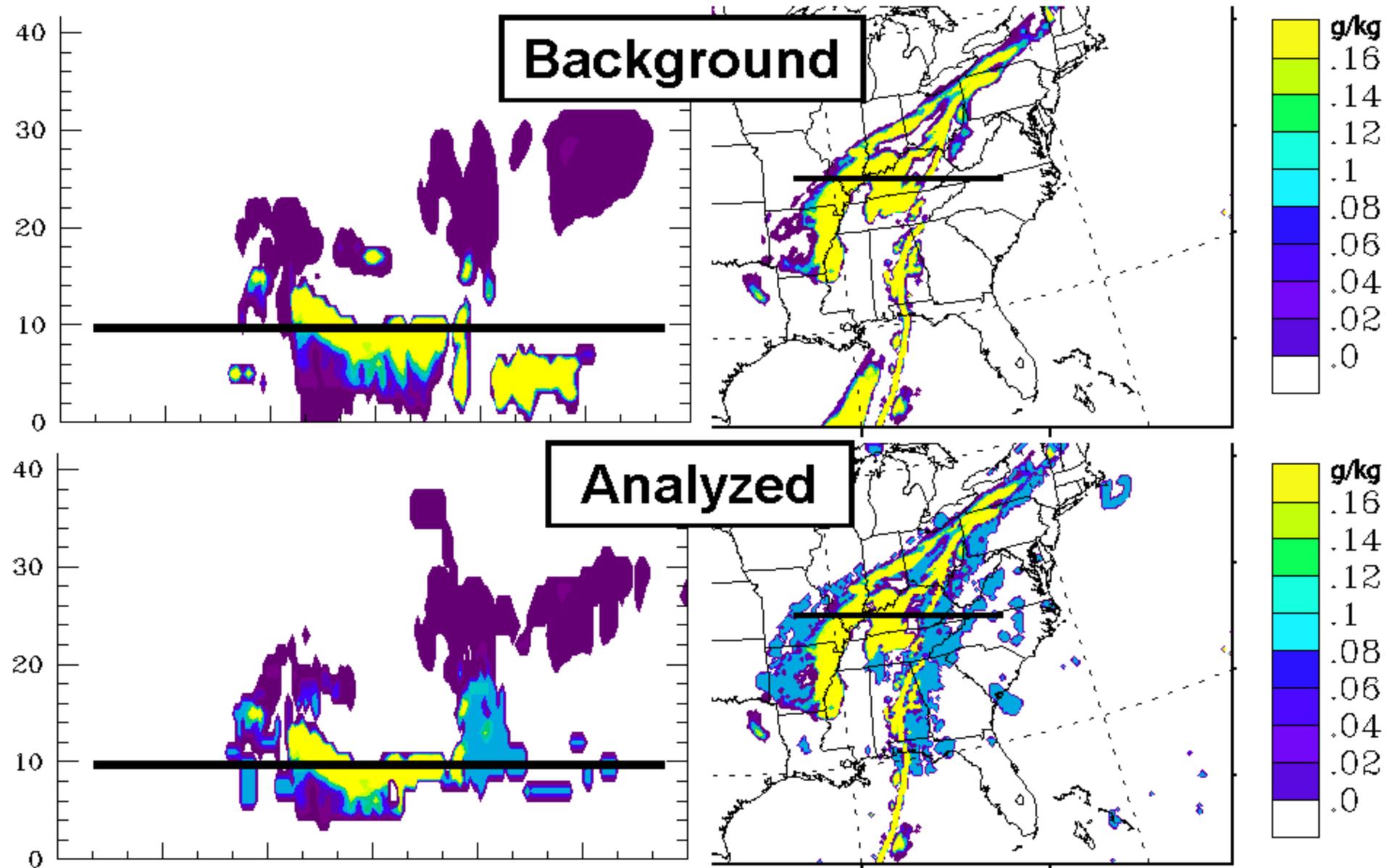
Surface observation assimilation -- ongoing

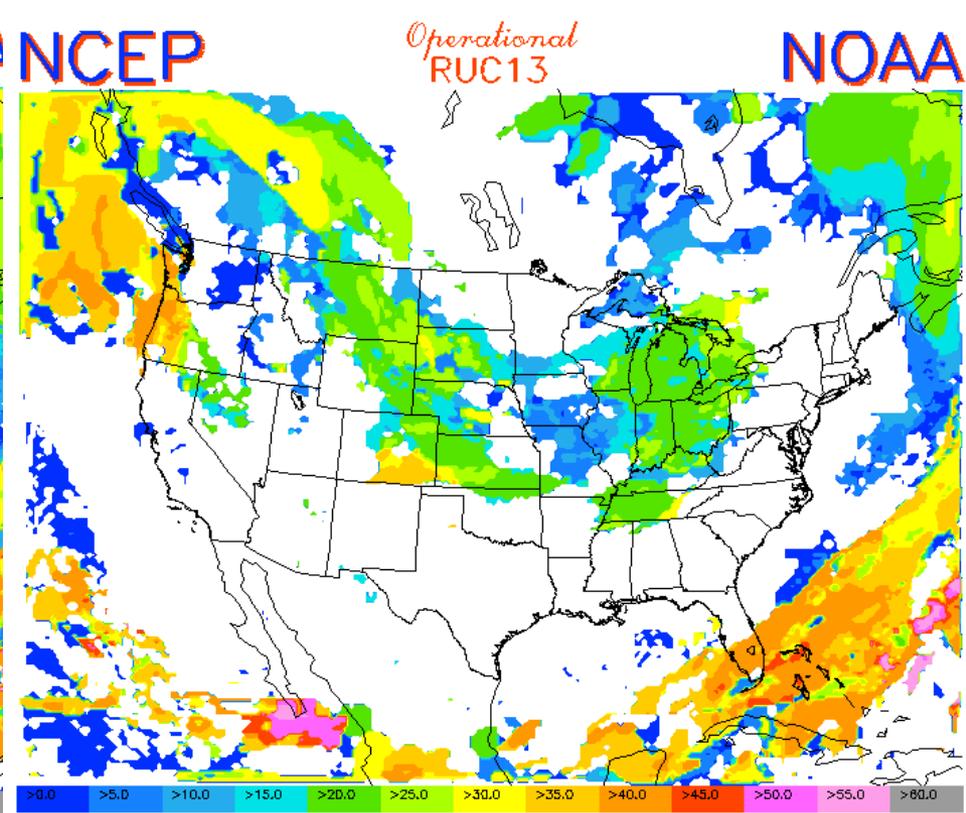
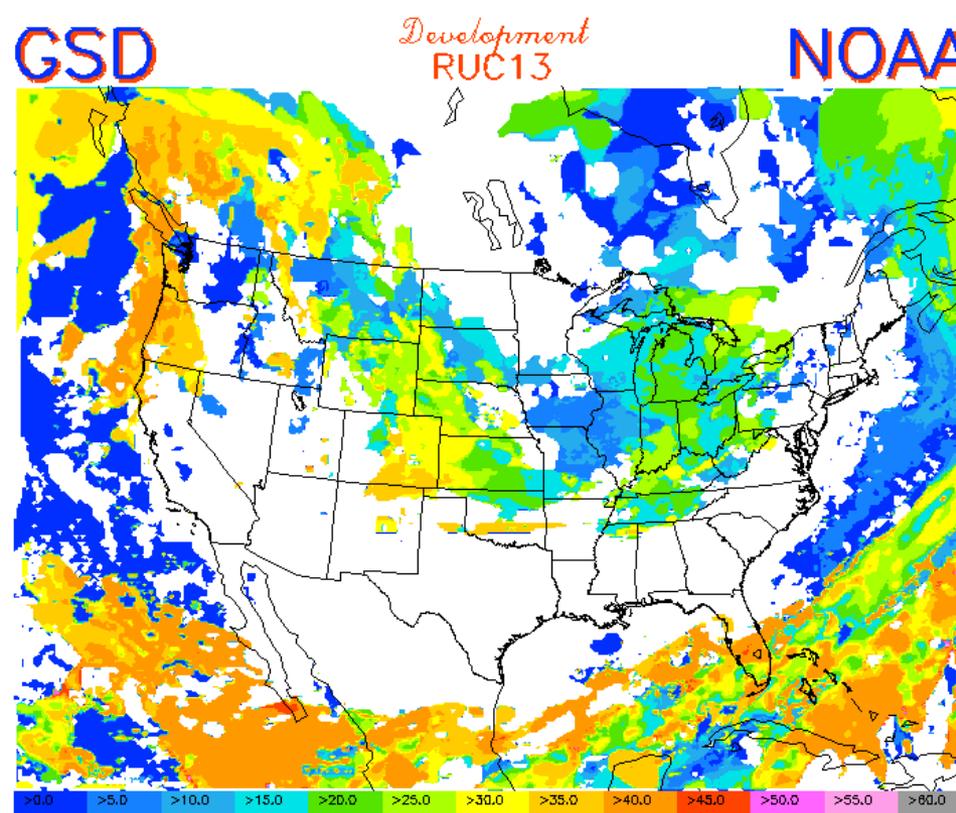
- Account for model vs. terrain height difference
- Apply surface observation innovations through PBL
- Select best background for coastal observations

Modify background with cloud observations



$Q_c + Q_i$ Cross-section and K=10





**ESRL-experimental RUC
- Assimilating
NASA LaRC CTT/CTP/WP**

**NCEP-operational RUC
- Assimilating
NESDIS CTT/CTP**

15z 14 Jan 2009 - 0h (analysis)

RUC processing for NASA Langley cloud/hydrometeor assimilation

Use GOES cloud-top pres/temp. similar to that for
NESDIS GOES cloud product

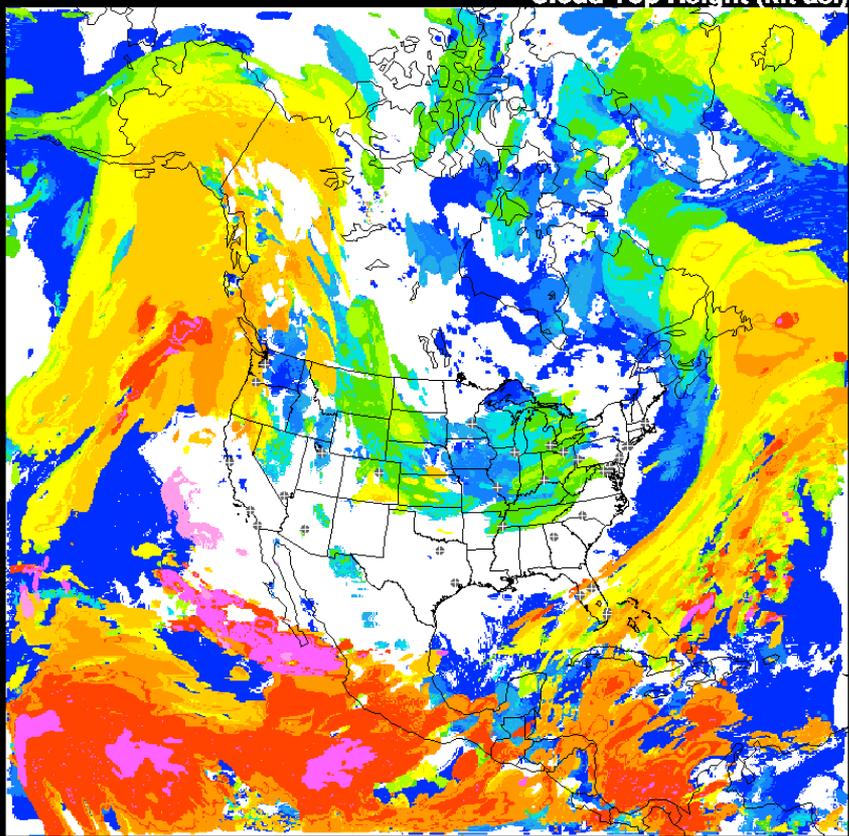
Larger horizontal coverage

- NASA - about 60% coverage of RUC domain
- NESDIS - about 32% coverage of RUC domain

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RR-CYCLED 01/14/2009 (15:00) 0 hr fcst

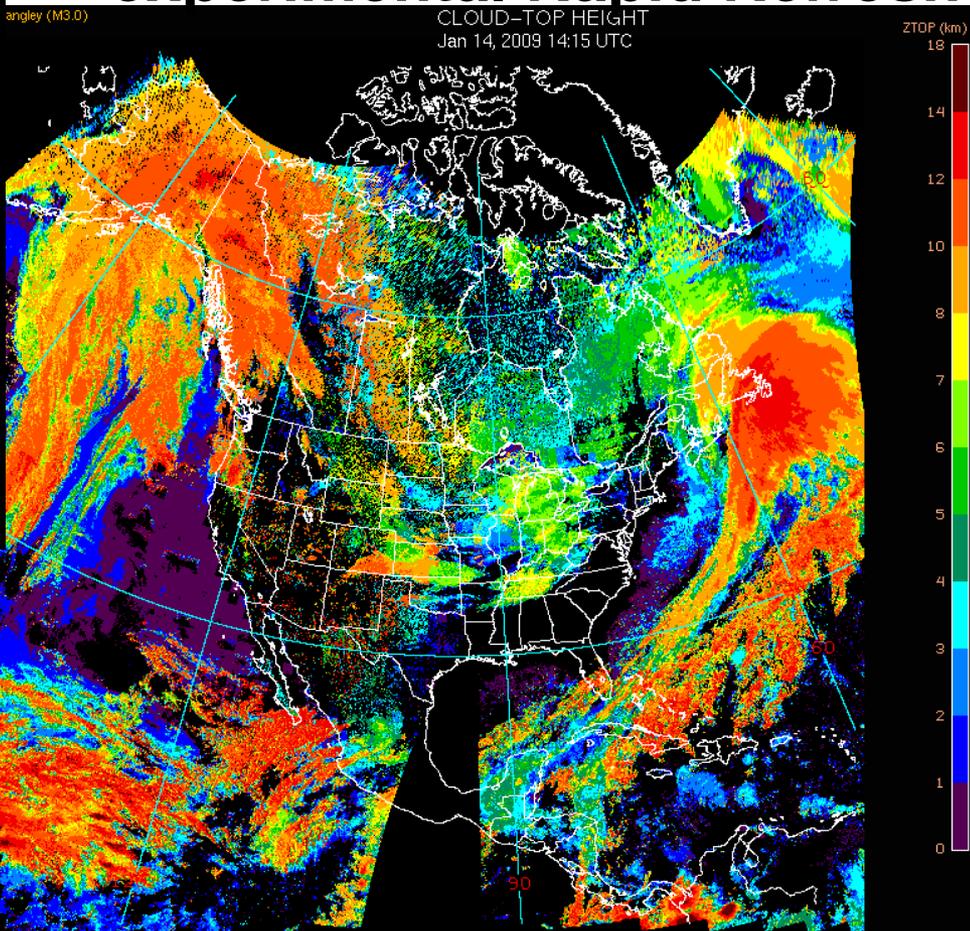
Valid 01/14/2009 15:00 UTC
Cloud Top Height (kft asl)



0 5 10 15 20 25 30 35 40 45 50 55 60

**Rapid Refresh - 0h cl-top
15z - 14 Jan 2009
Assimilating NESDIS-
RUC cloud data**

**NASA-LaRC
Cloud-top retrieval
1415z - 14 Jan 2009
- Toward assimilation in
experimental Rapid Refresh**



CLOUD-TOP HEIGHT
Jan 14, 2009 14:15 UTC

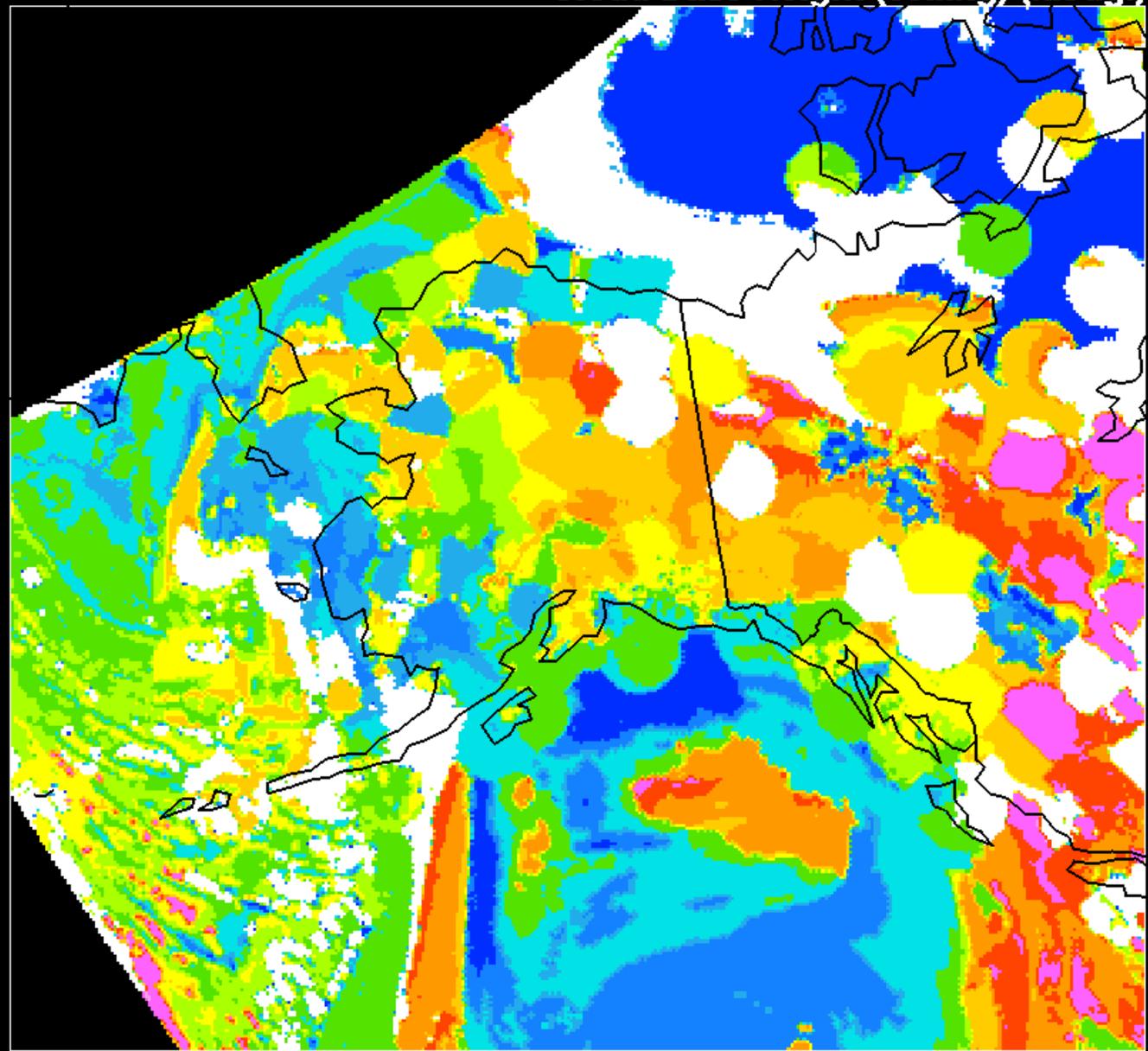
ZTOP (km)

18
14
12
10
8
7
6
5
4
3
2
1
0

RR-CYCLED 03/11/2009 (15:00) 0 hr fcst

Valid 03/11/2009 15:00 UTC

Cloud Base Height (ceiling) (kft agl)



**RR analysis -
Diagnosed
ceiling from 3-d
hydrometeors**

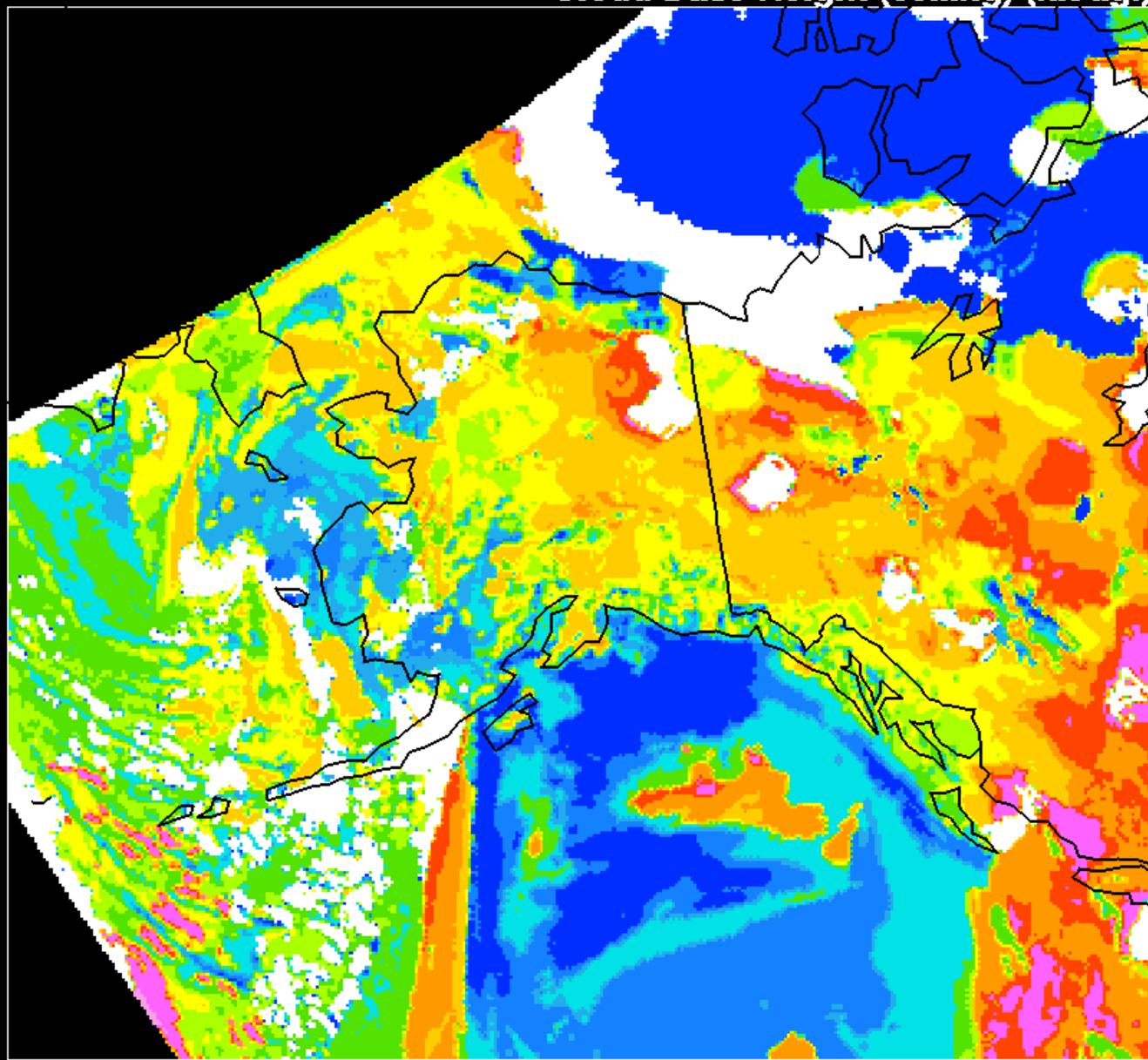
-11 March 2009
1500 UTC

- "tuna can"
clearing soon to
be corrected

RR-CYCLED 03/11/2009 (15:00) 1 hr fcst

Valid 03/11/2009 16:00 UTC

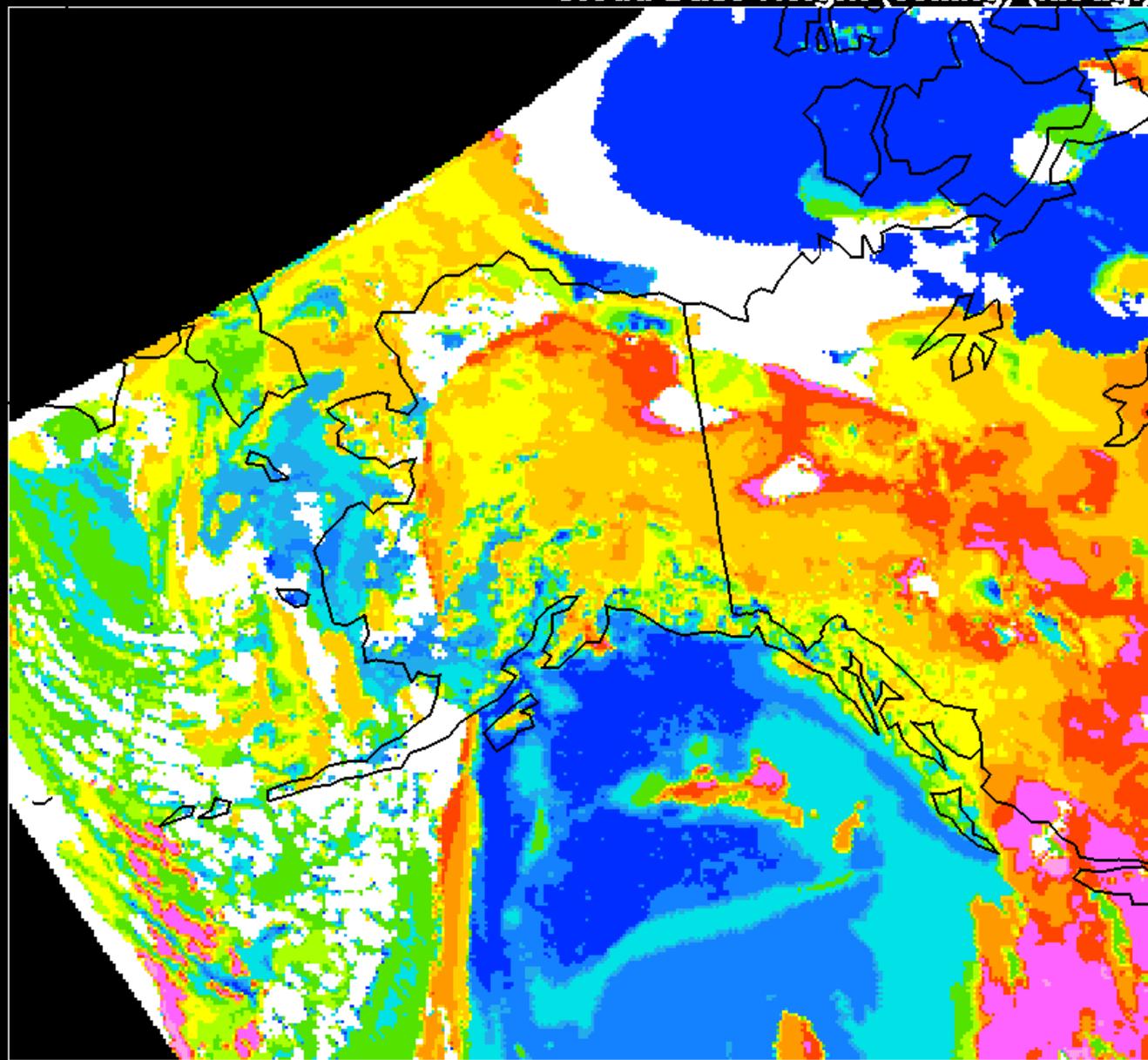
Cloud Base Height (ceiling) (kft agl)



RR-CYCLED 03/11/2009 (15:00) 2 hr fcst

Valid 03/11/2009 17:00 UTC

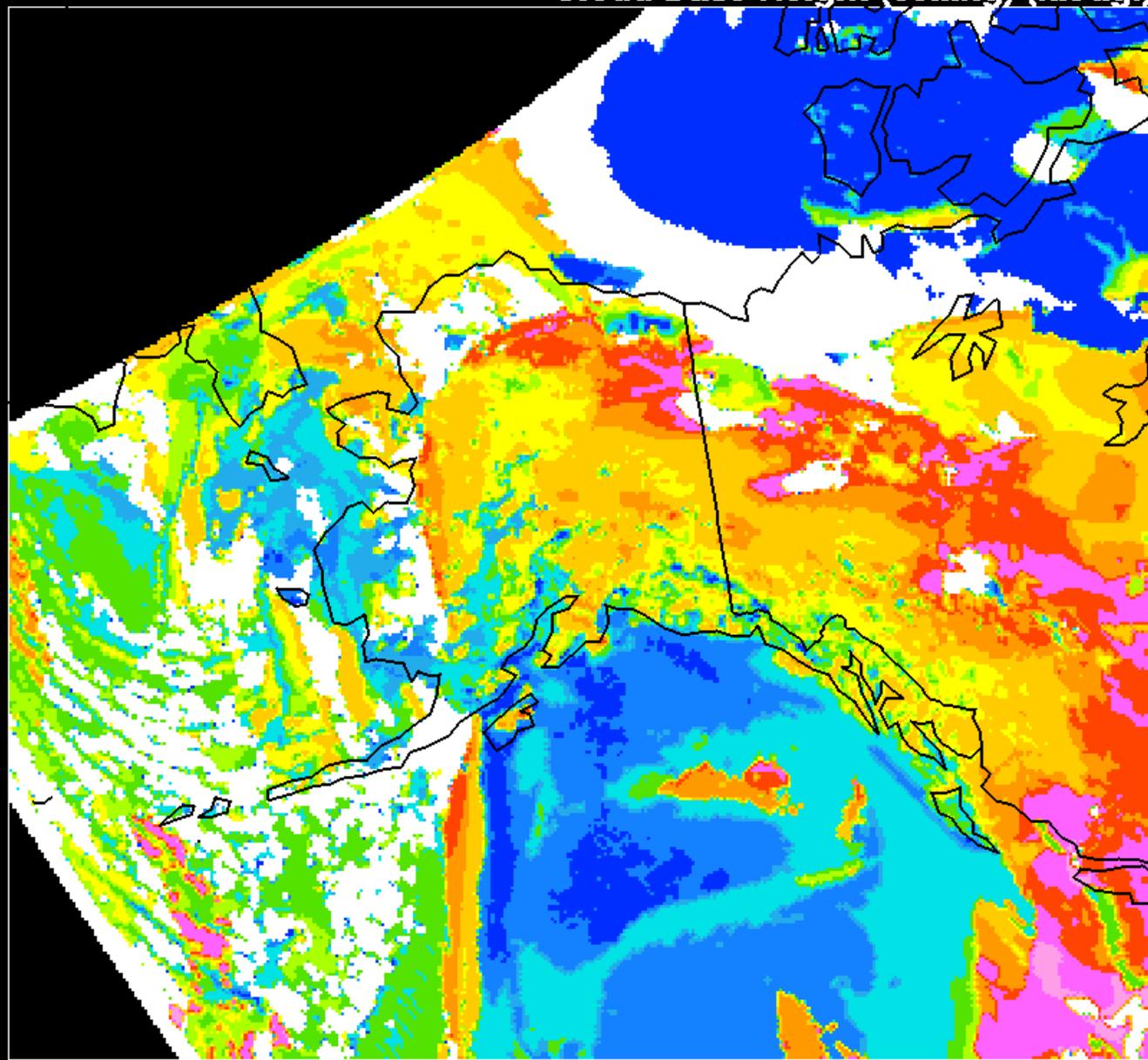
Cloud Base Height (ceiling) (kft agl)



RR-CYCLED 03/11/2009 (15:00) 3 hr fcst

Valid 03/11/2009 18:00 UTC

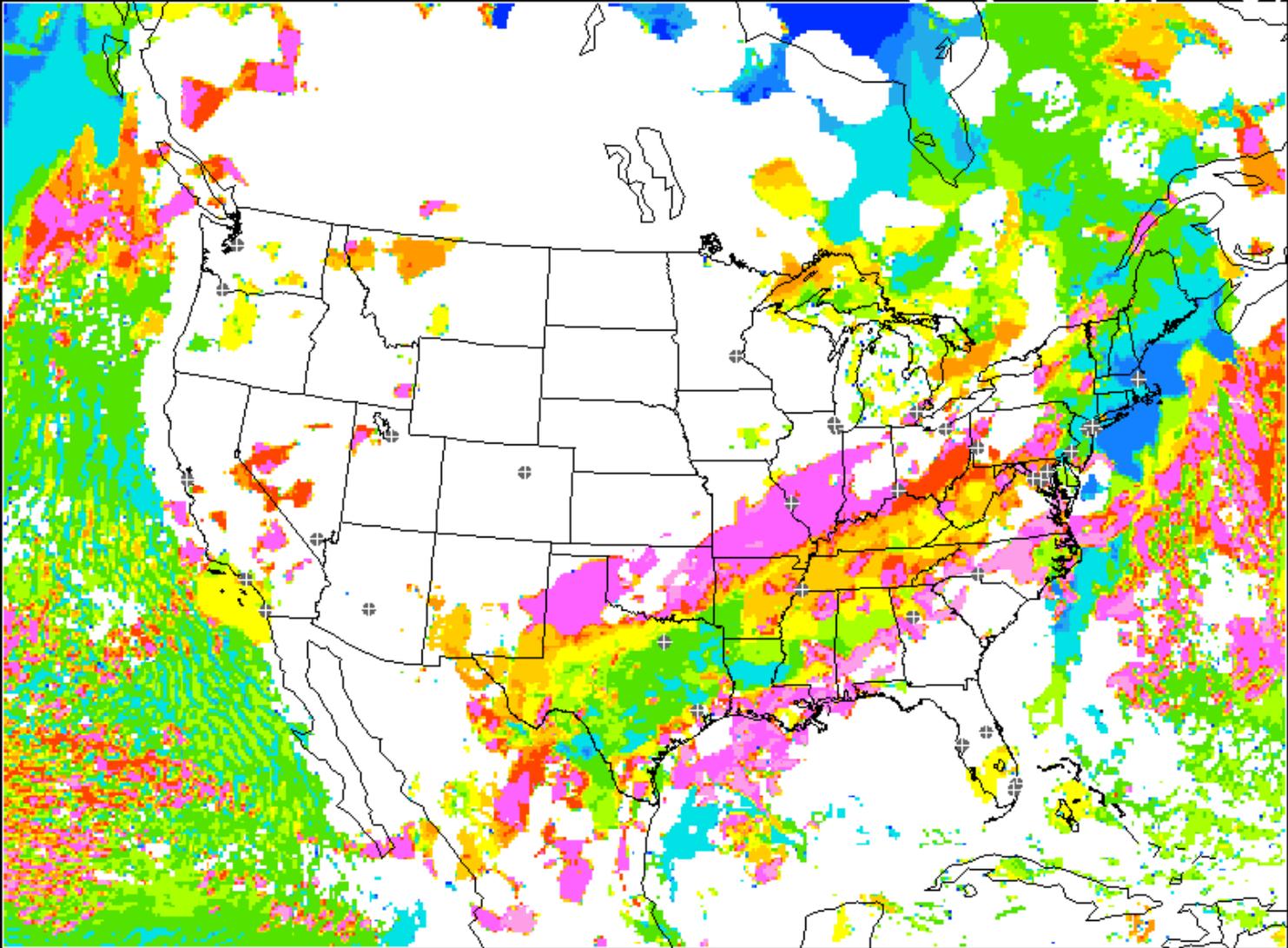
Cloud Base Height (ceiling) (kft agl)



RR-CYCLED 03/11/2009 (18:00) 0 hr fcst

Valid 03/11/2009 18:00 UTC

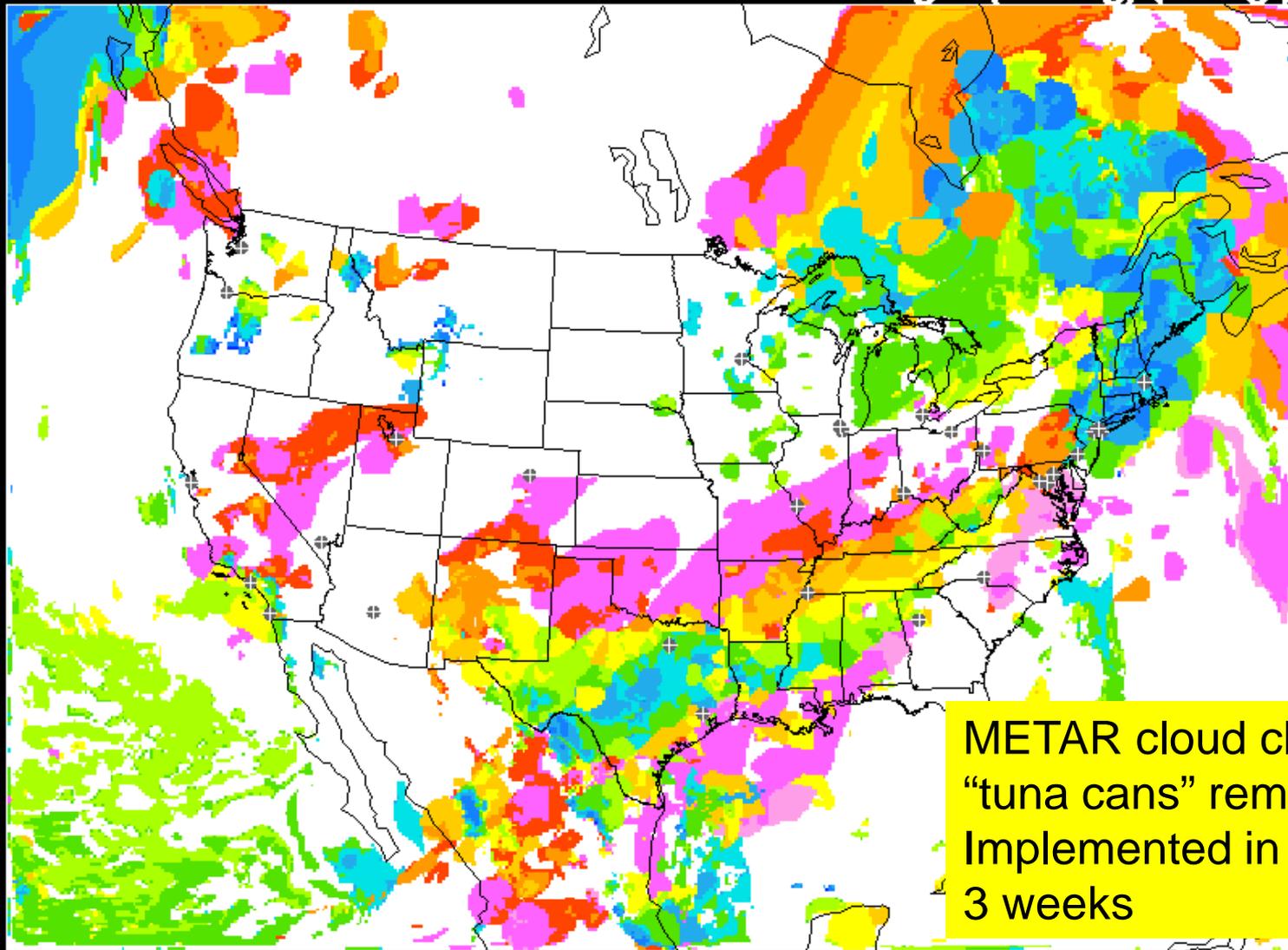
Cloud Base Height (ceiling) (kft agl)



RUC 13KM 03/11/2009 (18-00) 0 hr fcst

Valid 03/11/2009 18:00 UTC

Cloud Base Height (ceiling) (kft agl)



METAR cloud clearing
“tuna cans” removed in RUC,
Implemented in RR in next 2-
3 weeks

0 .1 .3 .5 1 2 3 5 10 15 20 30

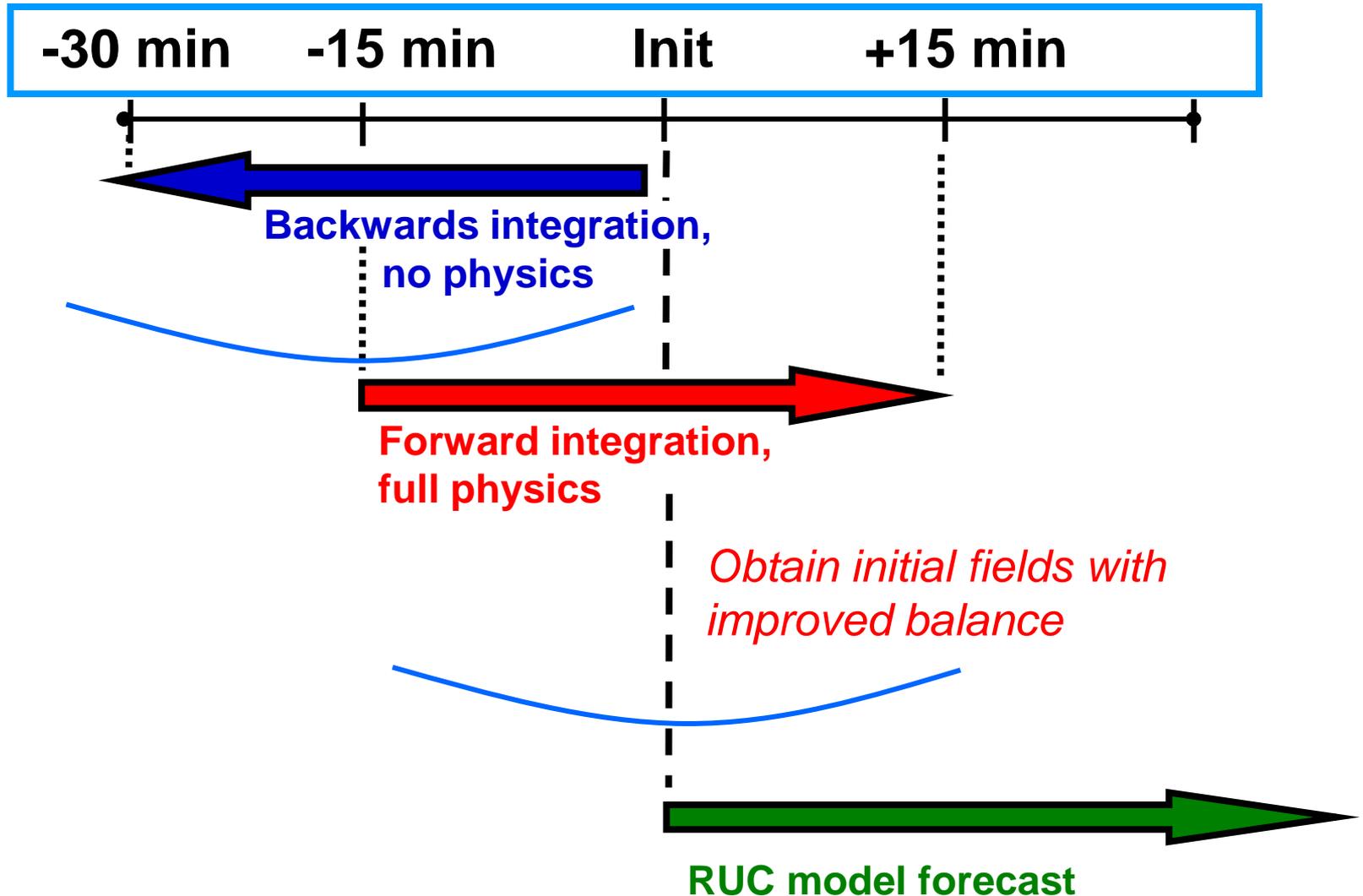
Major RR fixes still needed

- **Correct WRF crashes near RR boundary related to hourly GSI assimilation**
- **Decrease Obs errors for GSI**
 - Raobs, profiler, aircraft, GPS?, surface
- **Ice/snow initialization and radiation**
 - Ice stays too warm, snow on ice cannot cool off
- **Surface observation innovation algorithms**
 - Elevation correction, PBL depth
- **Introduction of GOES (or MODIS) clouds up to ≥ 65 N**

RUC Diabatic Digital Filter Initialization (DDFI)

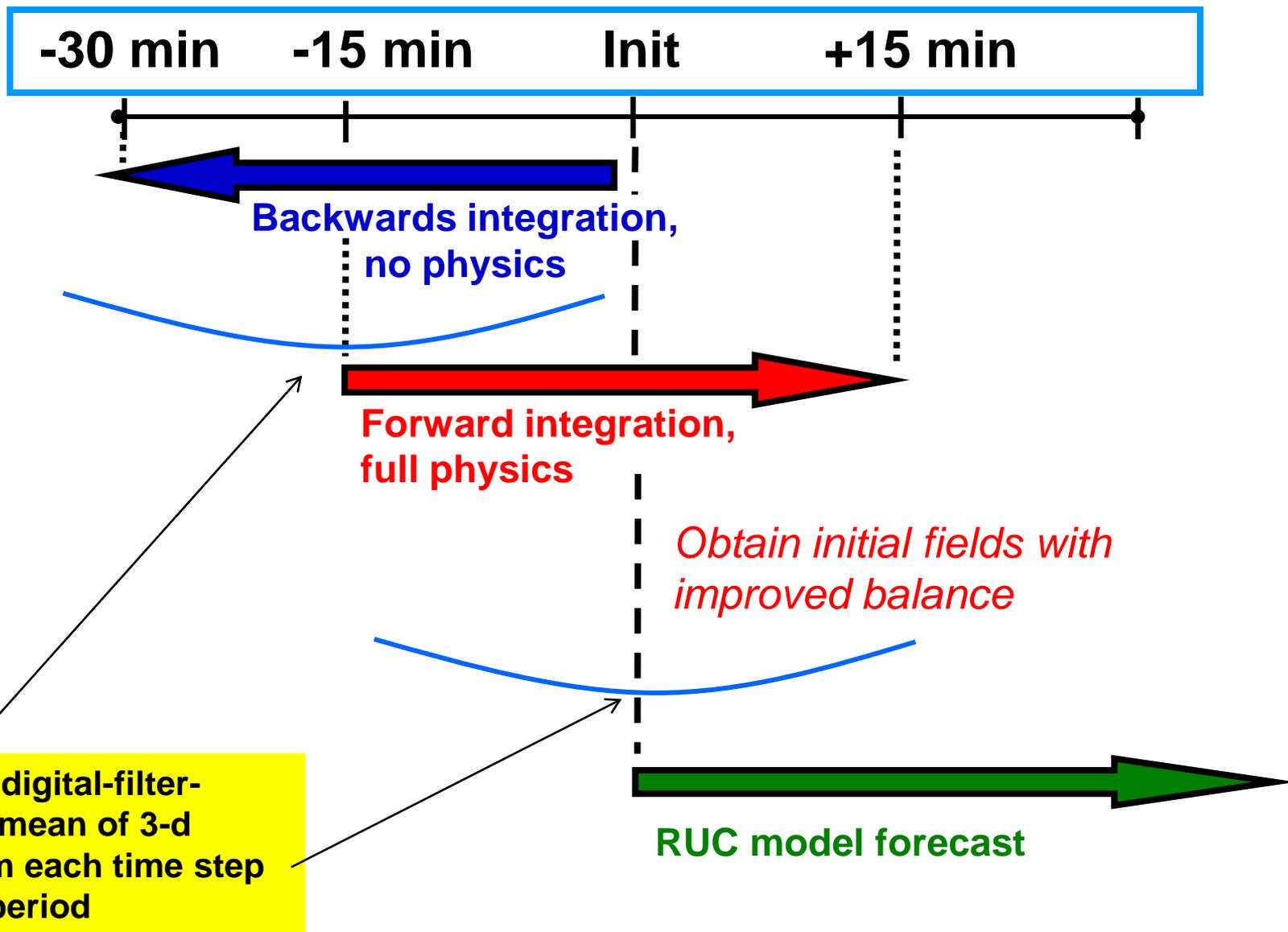
Initial DFI in RUC model at NCEP - 1998 - adiabatic DFI

Diabatic DFI introduced at NCEP - 2006



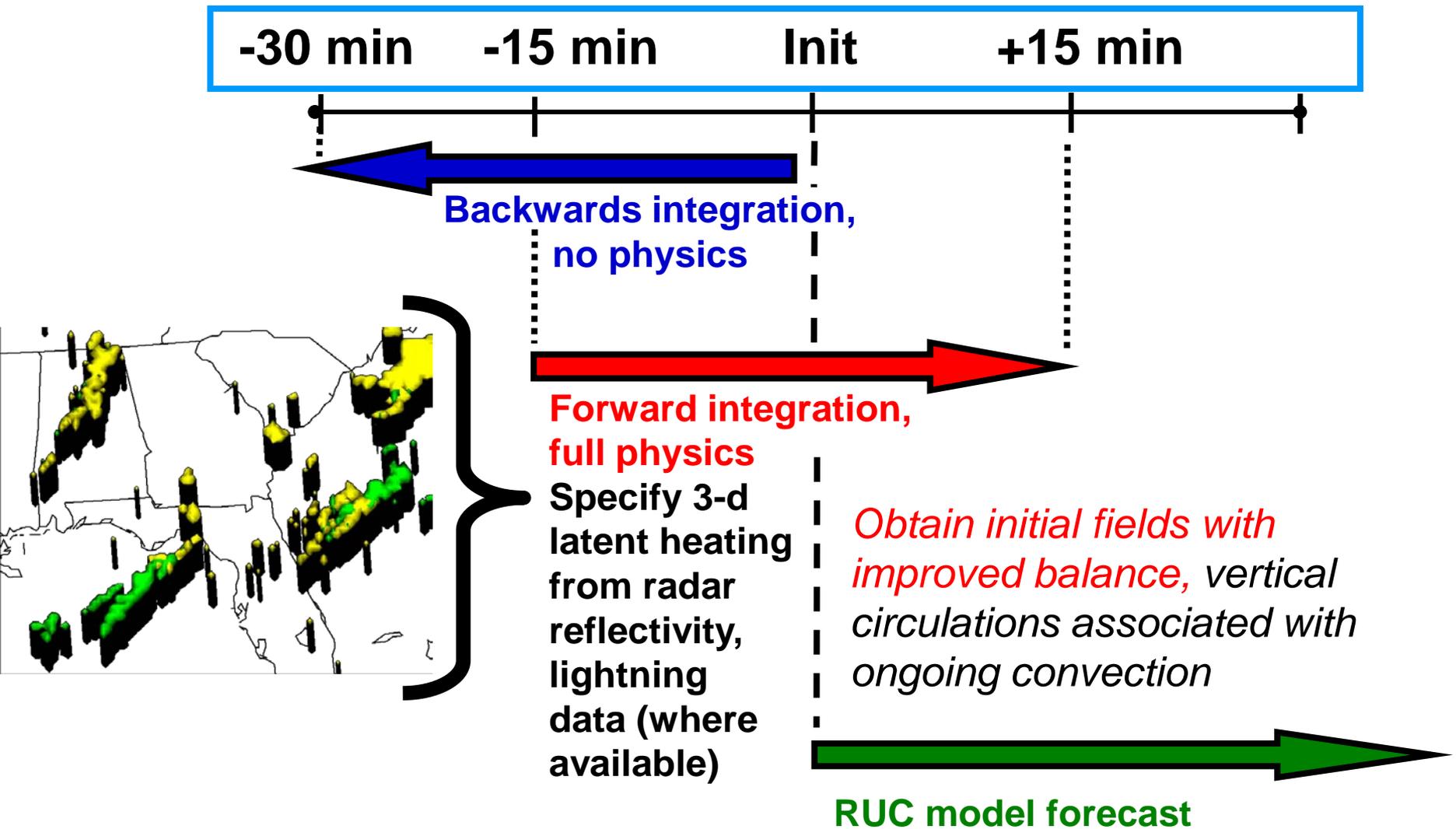
RUC Diabatic Digital Filter Initialization (DDFI)

Initial DFI in RUC model at NCEP - 1998 - adiabatic DFI
Diabatic DFI introduced at NCEP - 2006

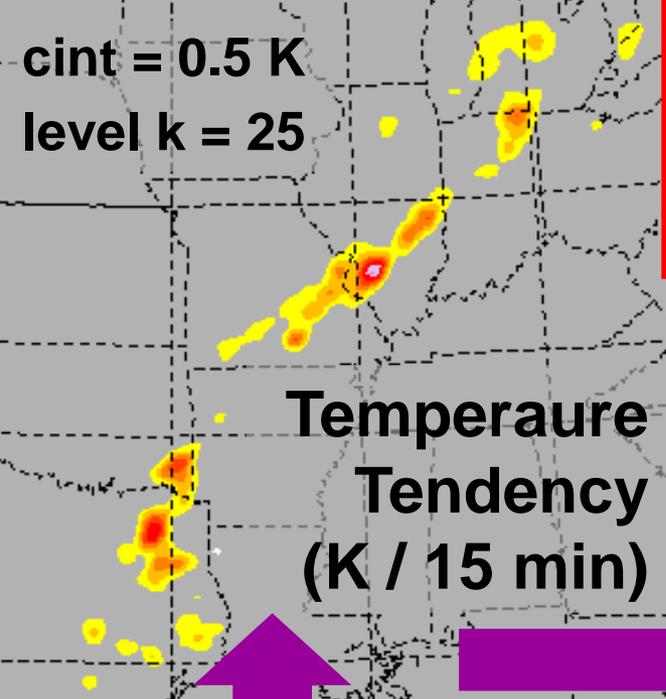


Diabatic Digital Filter Initialization (DDFI)

New - add assimilation of radar data

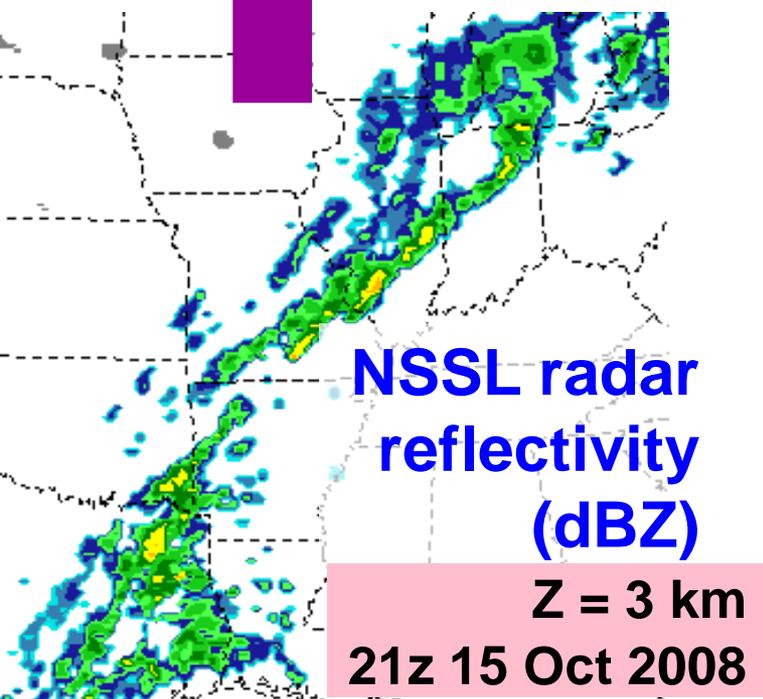
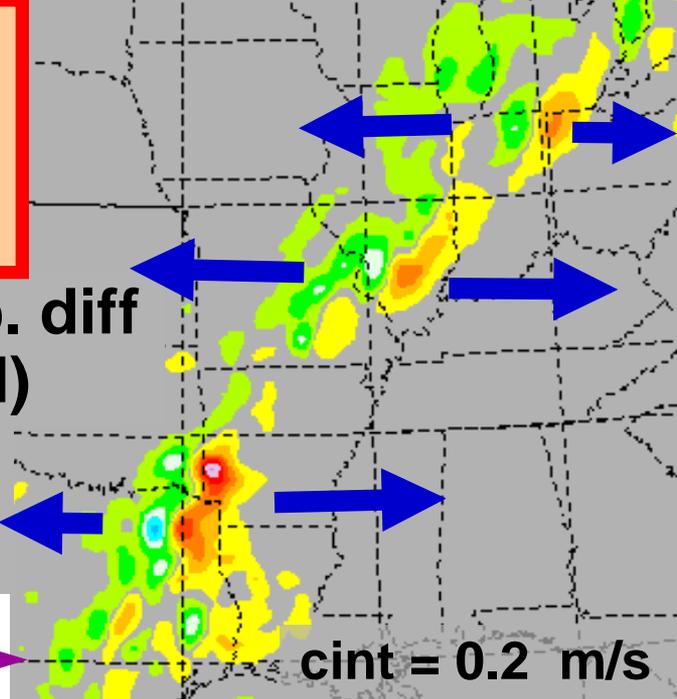


Radar reflectivity assimilation in RUC

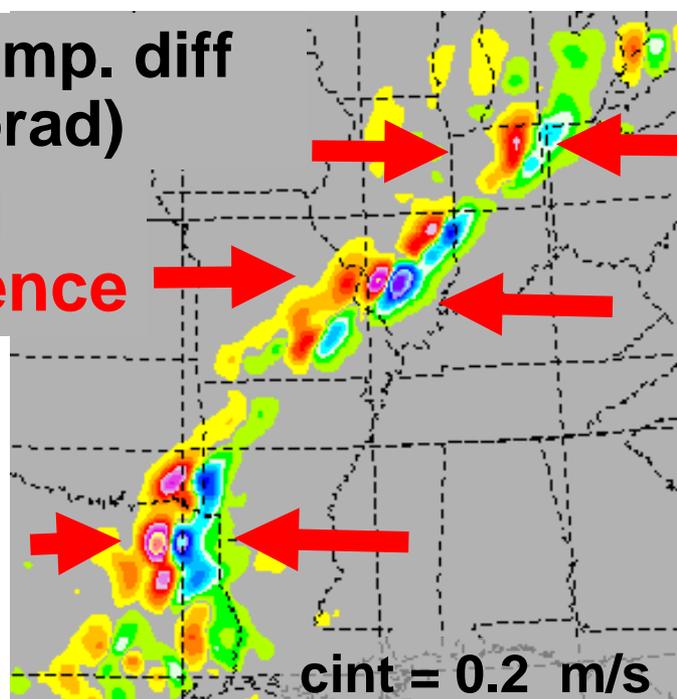


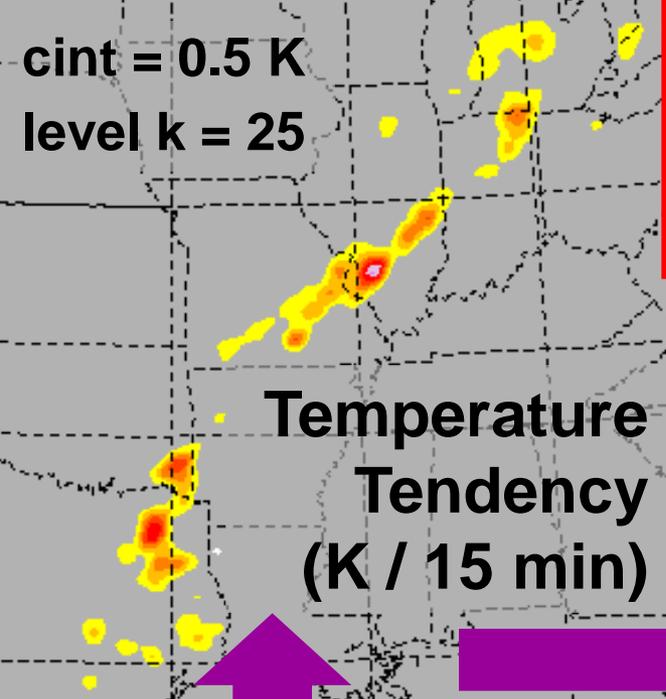
**Sample radar
assimilation
(one cycle)**

**K=35 U-comp. diff
(radar - norad)**
**Upper-level
Divergence**



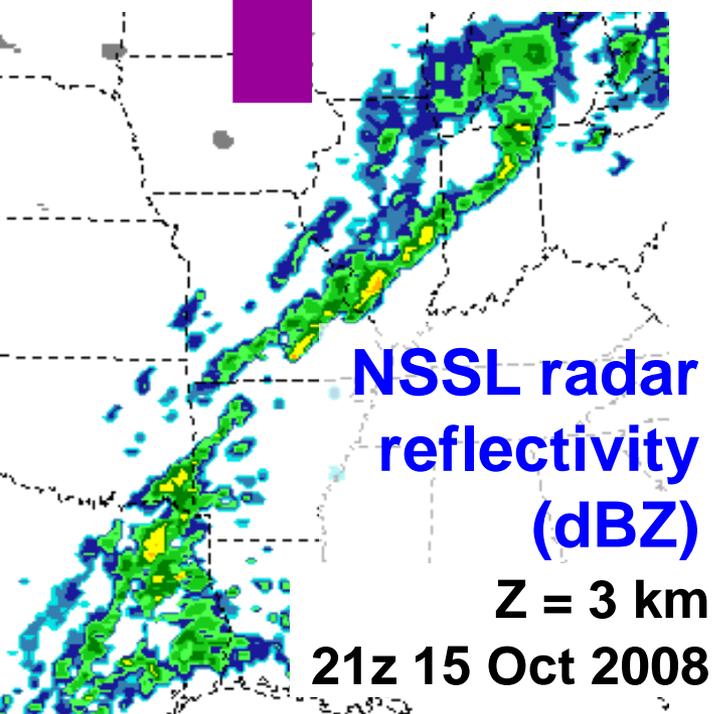
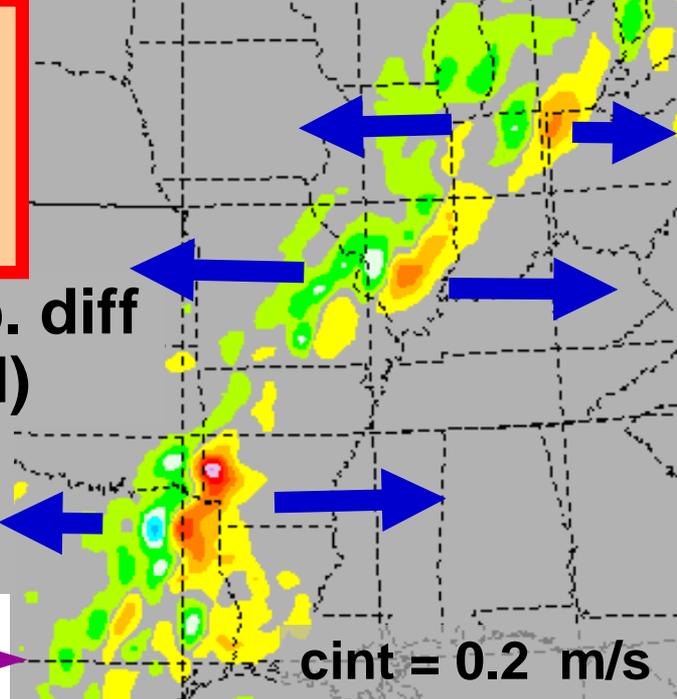
**K=15 U-comp. diff
(radar - norad)**
**Low-level
Convergence**





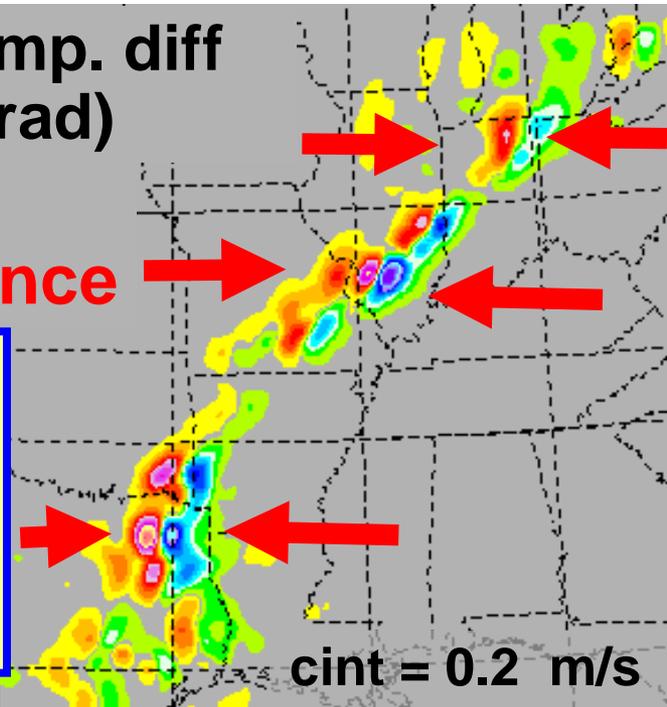
Sample radar assimilation (one cycle)

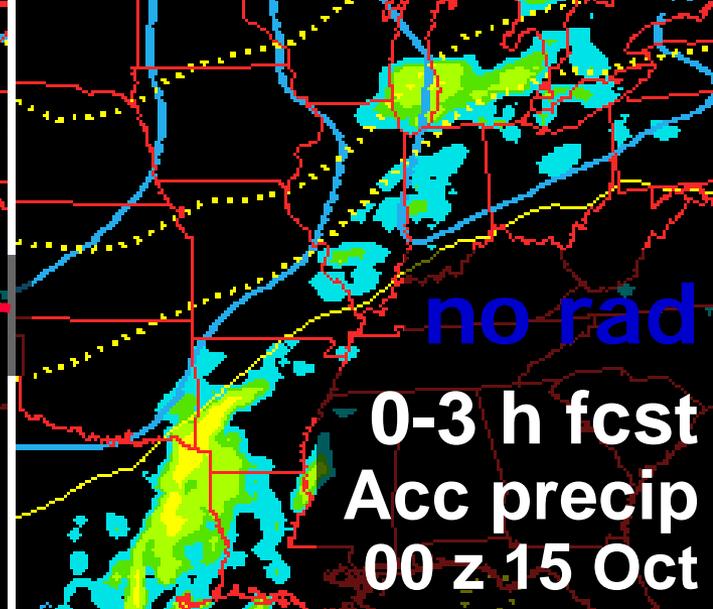
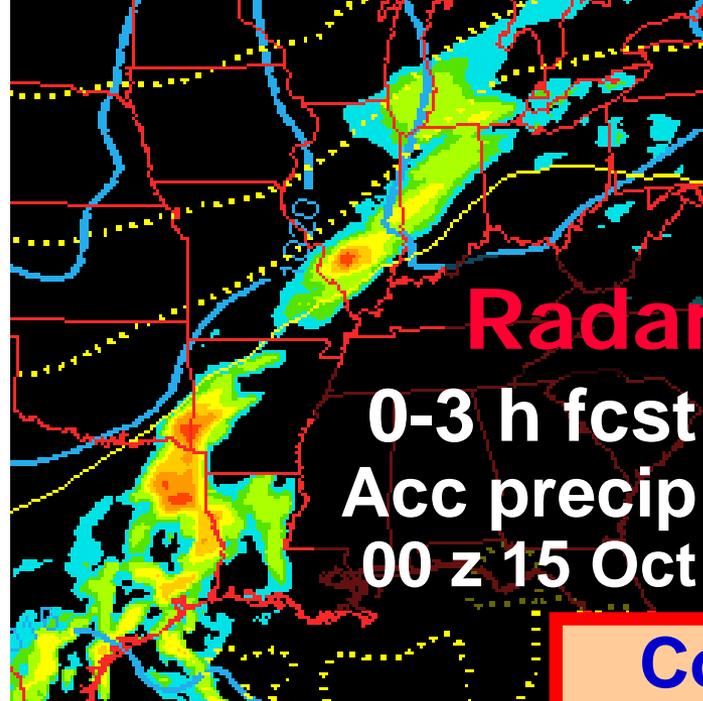
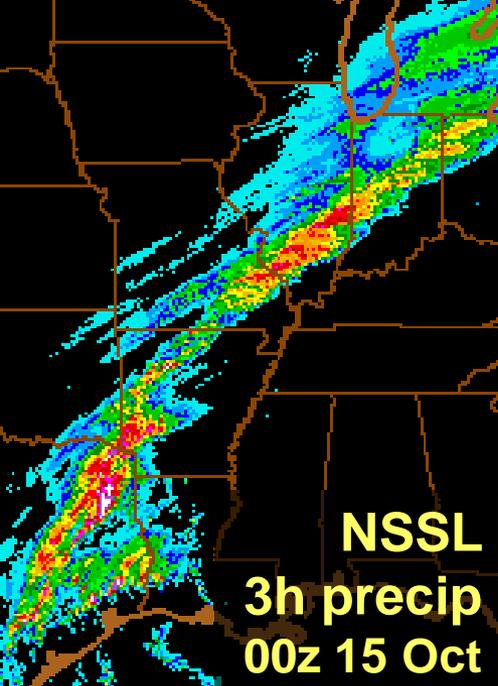
K=35 U-comp. diff (radar - norad)
Upper-level Divergence



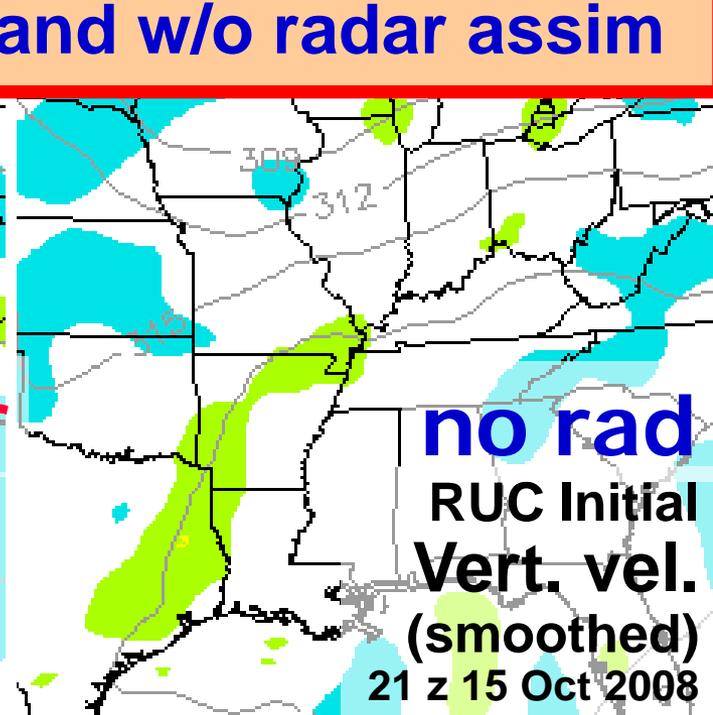
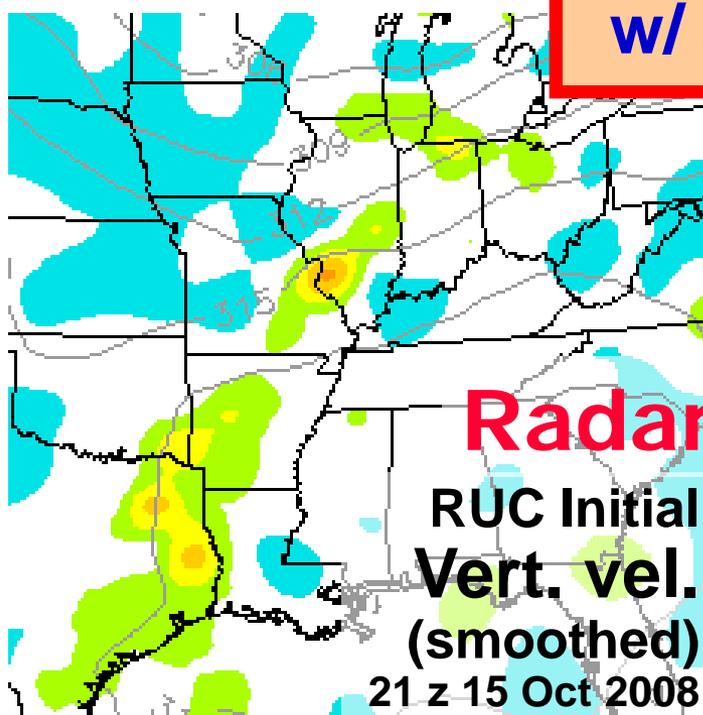
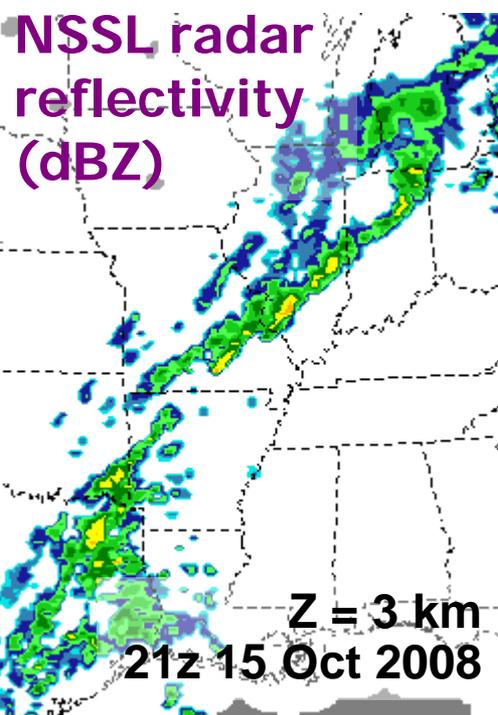
Radar assimilation applied each hour
Diff from single update -- cycle with radar assim

K=15 U-comp. diff (radar - norad)
Low-level Convergence



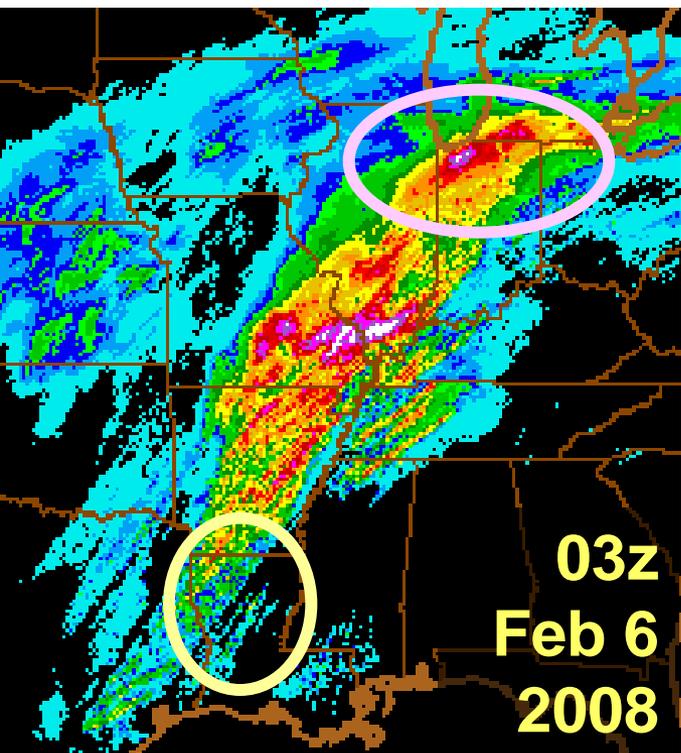


Compare RUC cycles w/ and w/o radar assim

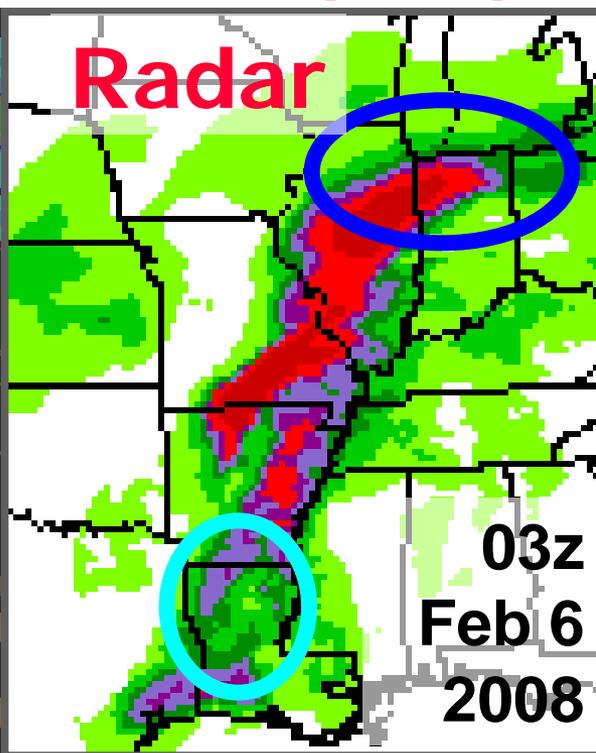


NCEP RUC parallel reflectivity assimilation example

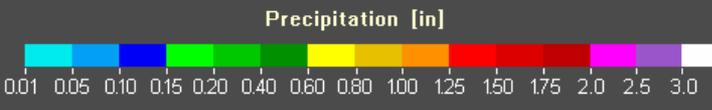
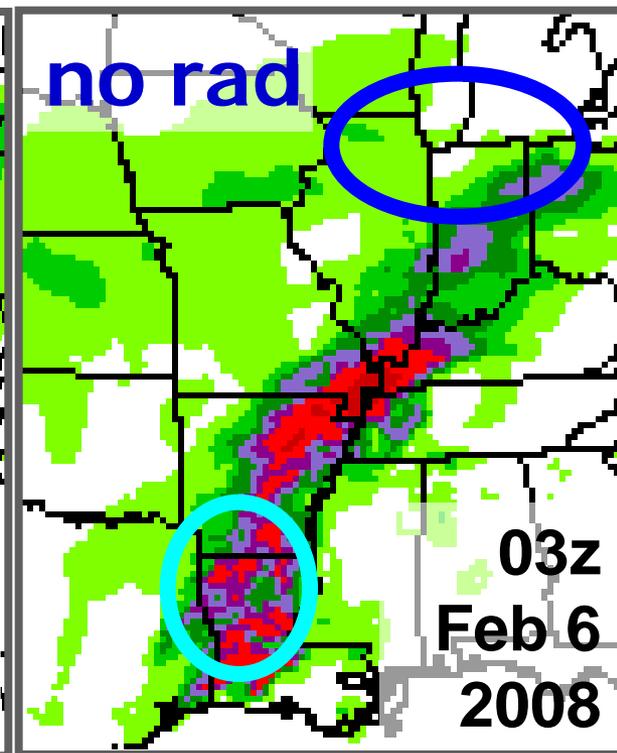
NSSL 3-h
precipitation



NCEP para RUC
0-3 fcst precip



NCEP oper RUC
0-3 fcst precip



(On RUC assimilation of TAMDAR data)

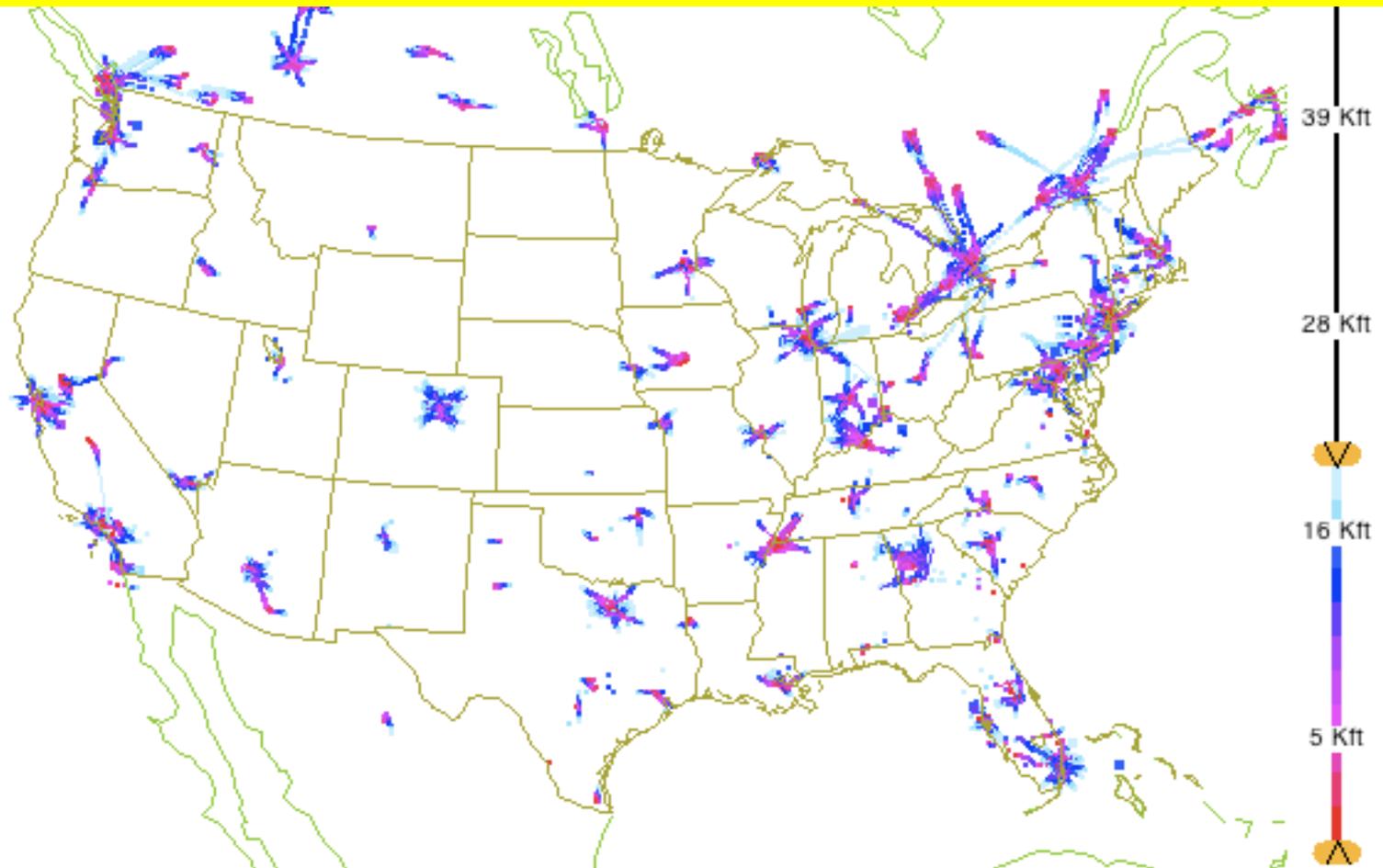
- AMDAR and TAMDAR definitions

- **“AMDAR” (Automated Meteorological Data and Recording) – are automatically sent from commercial aircraft, mostly large jets**
- **“TAMDAR” (Tropospheric AMDAR) – automatic reports from (currently) ~90 turboprops flying regionally in the US Midwest**
 - Provided by AirDat LLC
 - Agreement between AirDat LLC and
 - Mesaba – (regional Northwest subsidiary)
 - Republic/Chautauqua Airlines (Delta subsidiary)

**NCEP implementation for RUC and NAM
TAMDAR assimilation - Tues 16 Dec 2008**

Aircraft reports below 20 Kft **without** TAMDAR

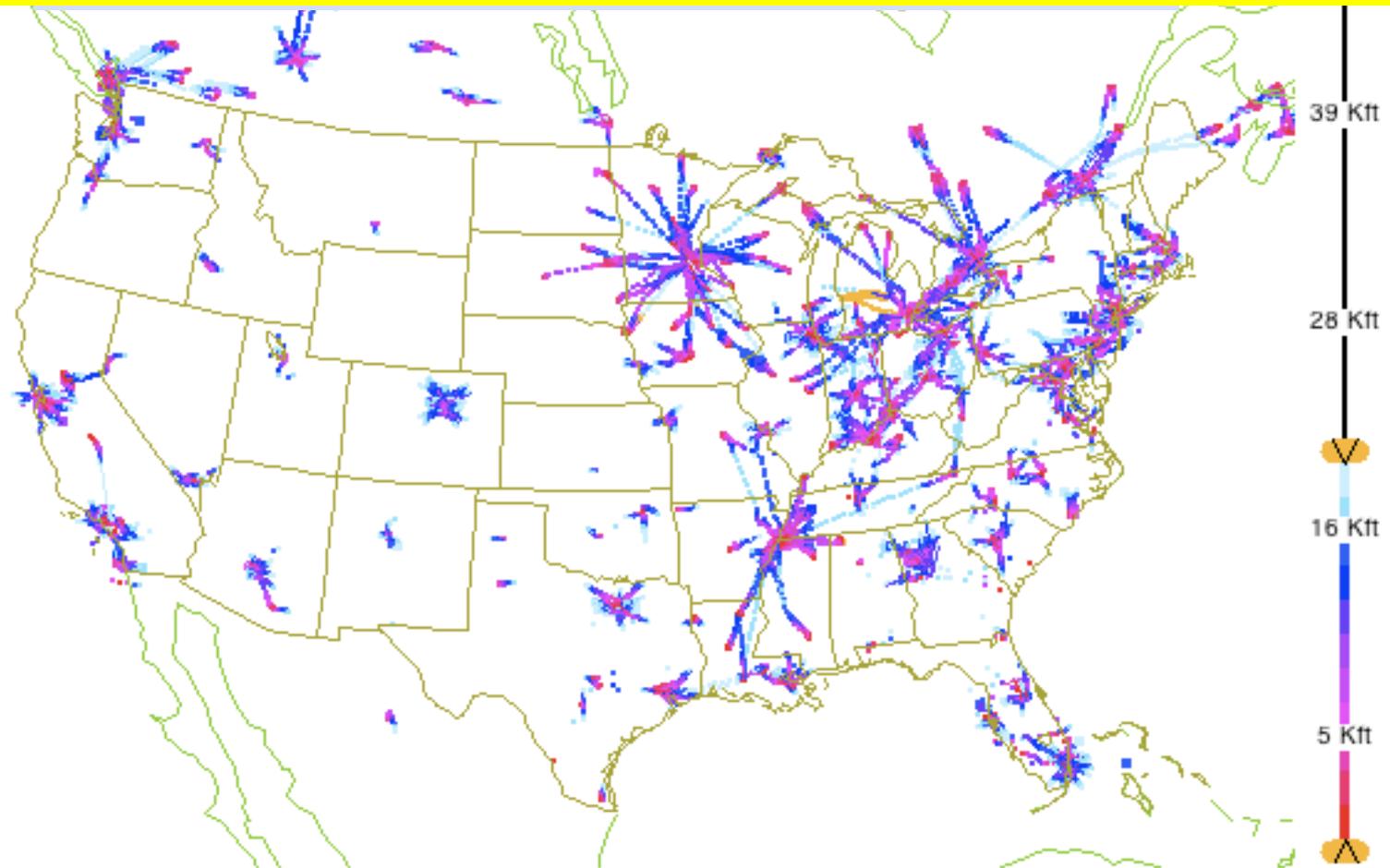
12-18z 9 October 2008



09-Oct-2008 12:00:00 -- 09-Oct-2008 17:59:59 (87152 obs loaded, 26951 in range, 5228 shown)

Aircraft reports below 20 Kft **including** TAMDAR

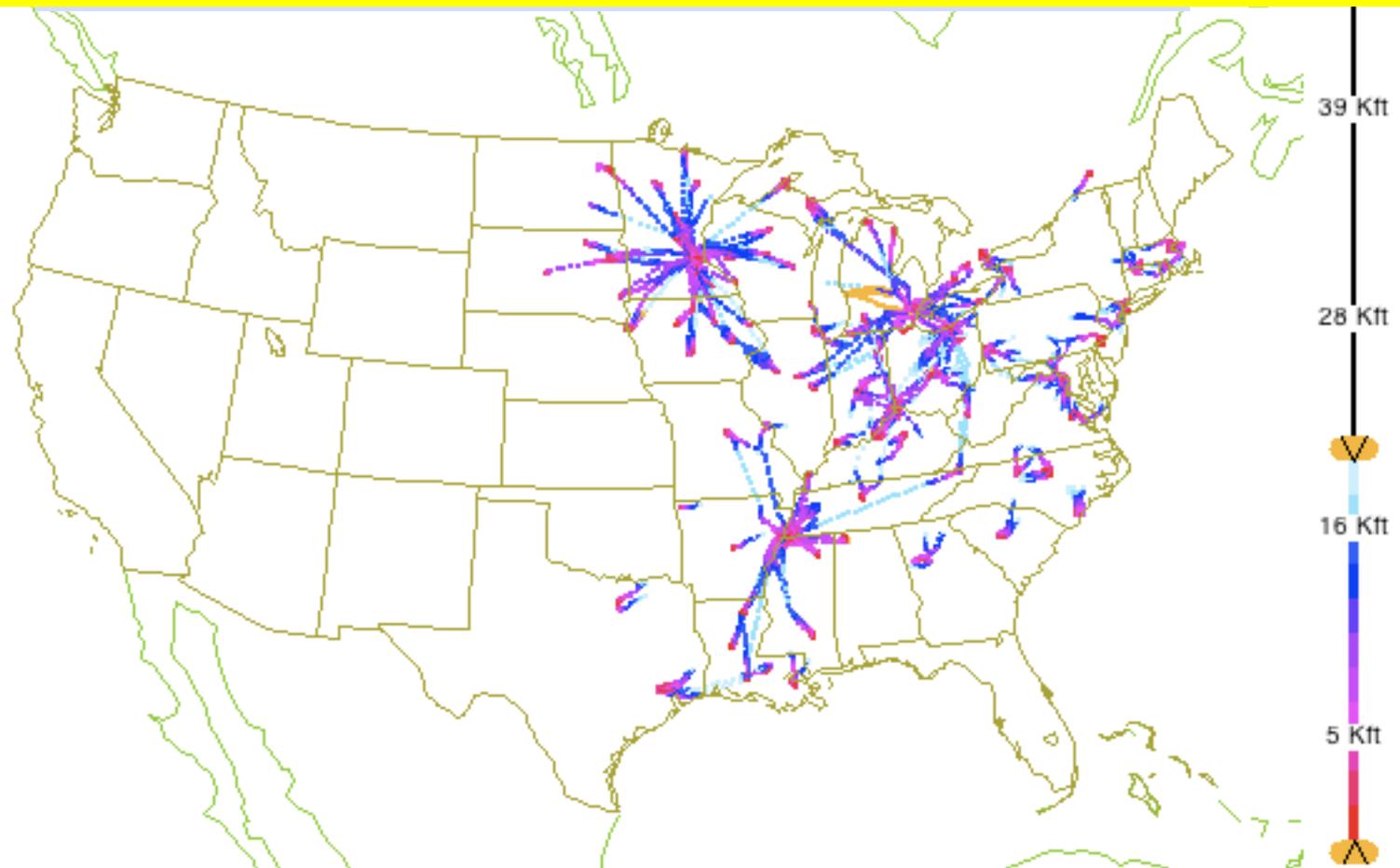
12-18z 9 October 2008



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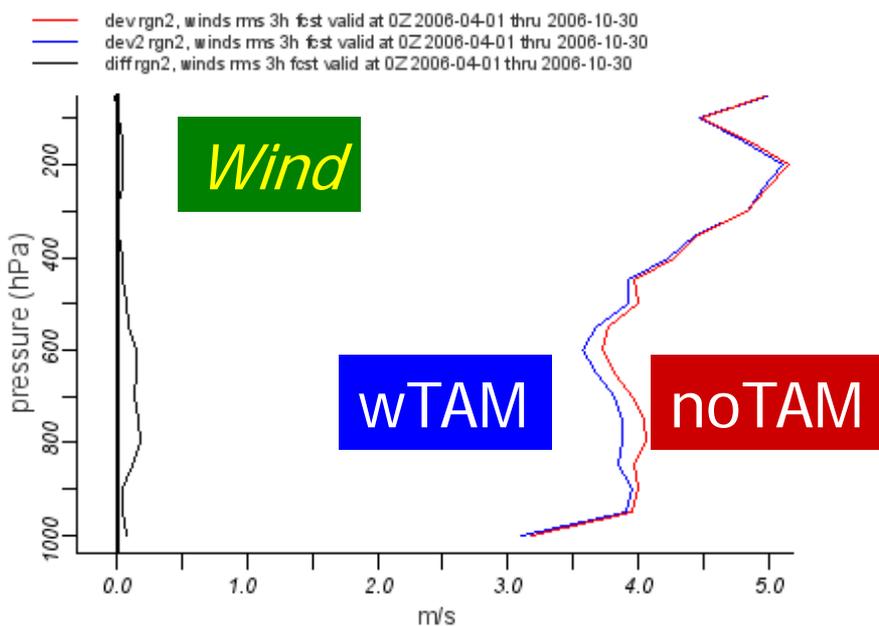
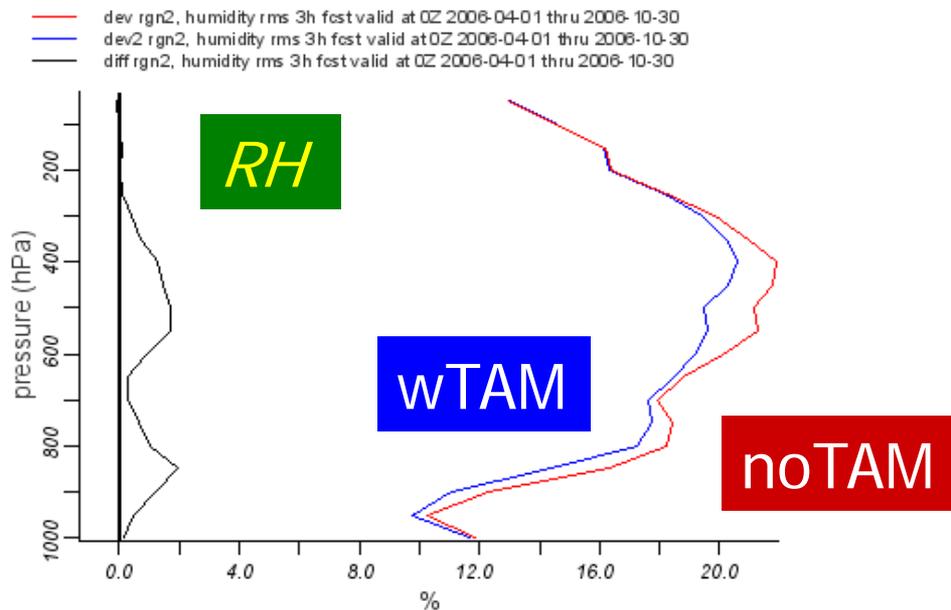
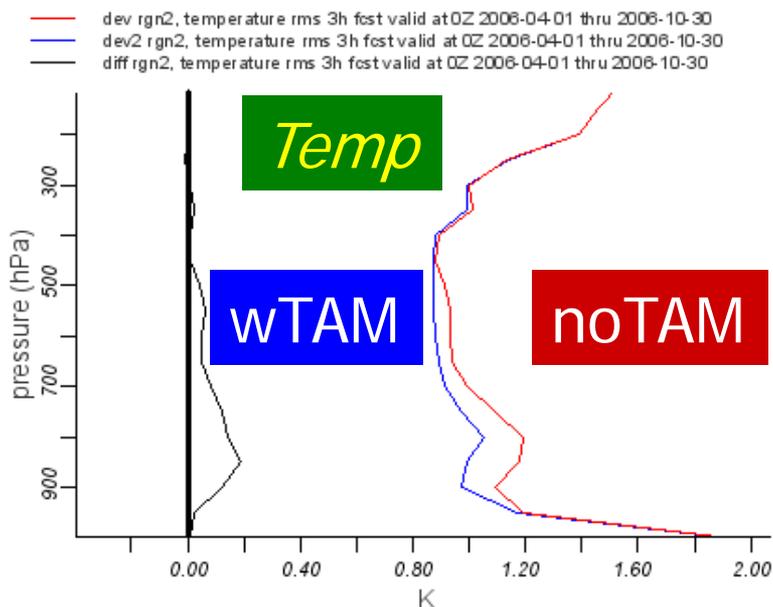
Aircraft reports below 20 Kft, **TAMDAR only**

12-18z 9 October 2008



09-Oct-2008 12:00:00 -- 09-Oct-2008 17:59:59 (87152 obs loaded, 9242 in range, 2828 shown)

3h Fcst errors – RUCdev (no TAMDAR), RUCdev2 (w/ TAMDAR)



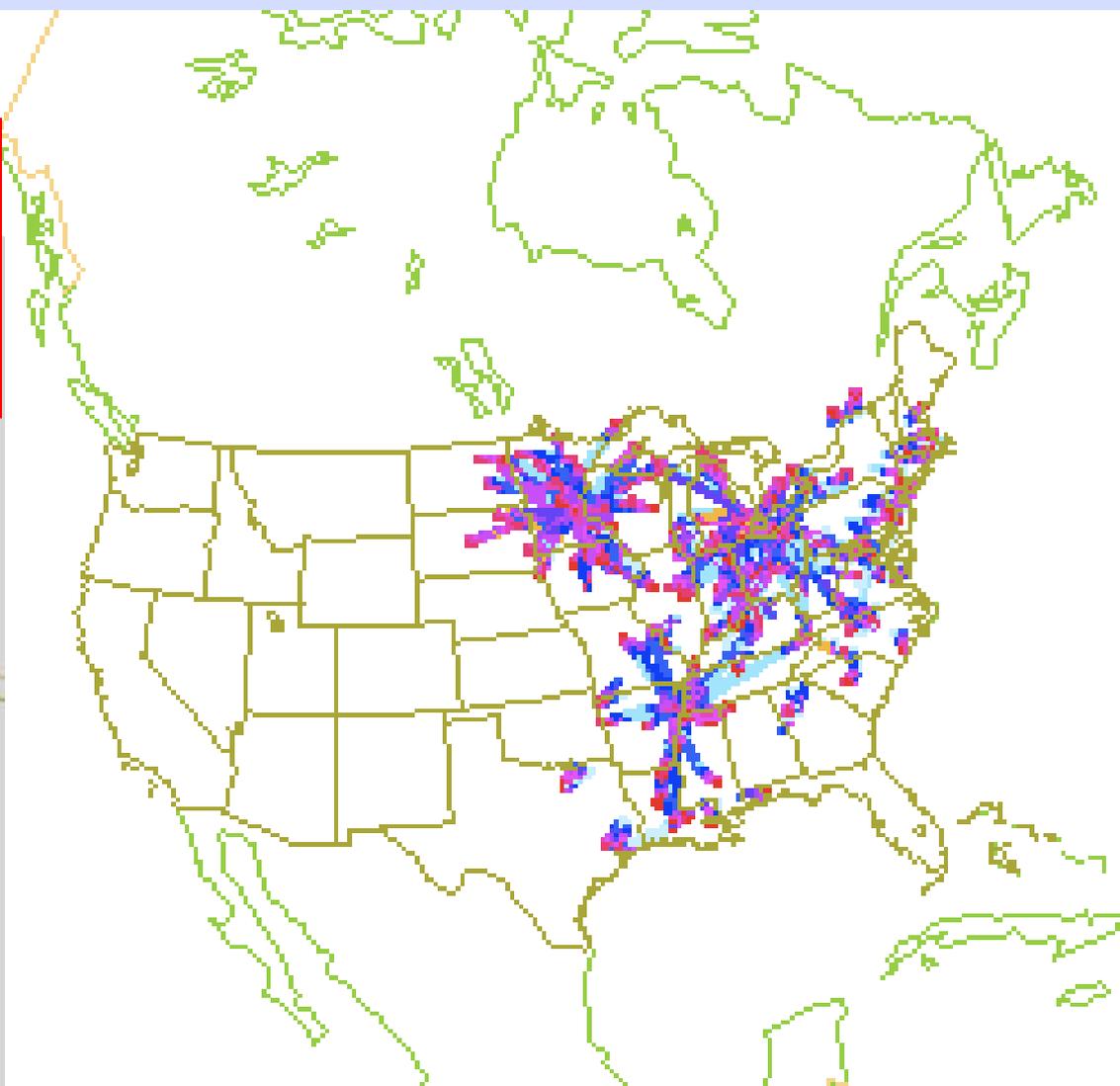
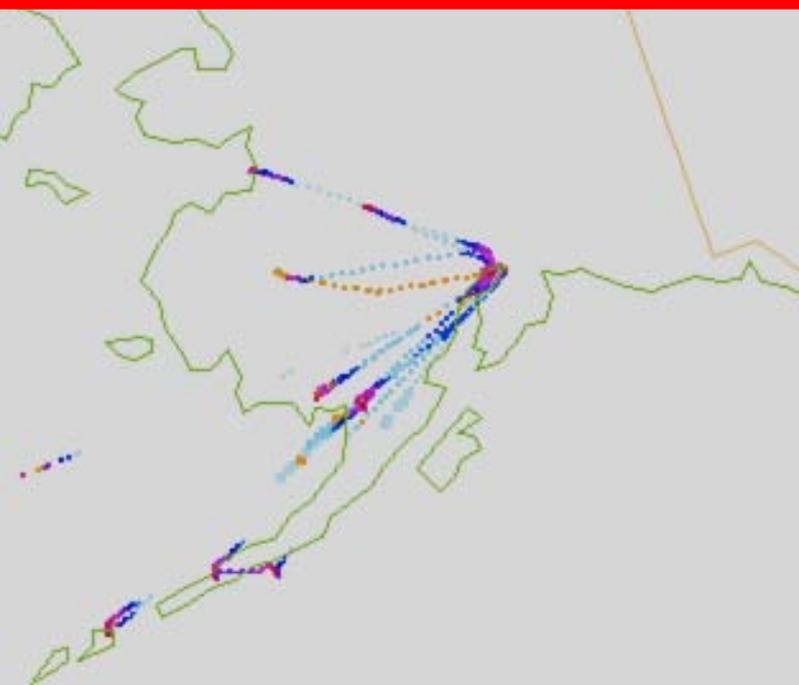
TAMDAR – regional aircraft with V/T/RH obs

GSD impact study with RUC parallel cycles

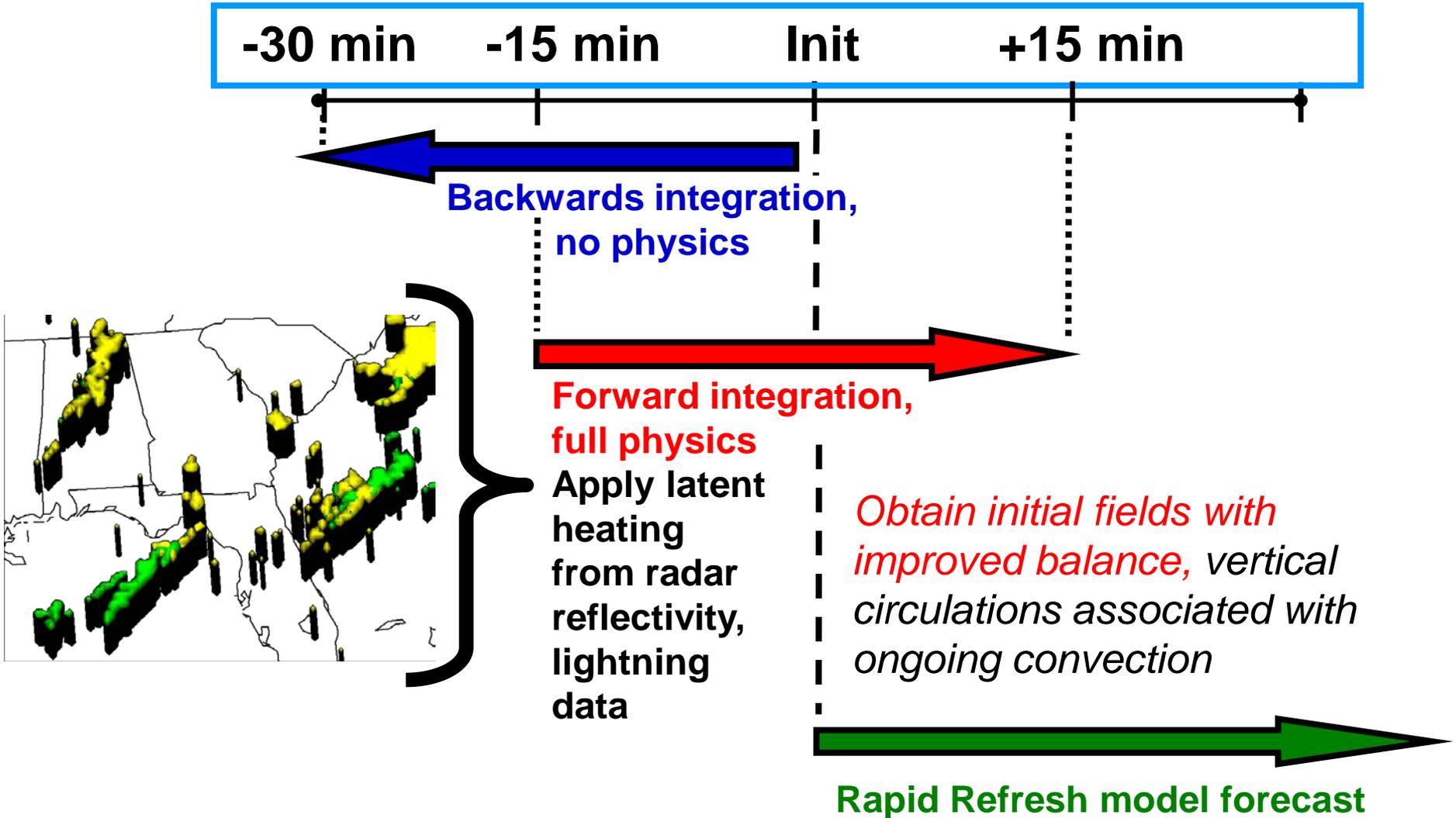
- 2005-2007 (ongoing)
- 10-30% reduction in RH, temperature, wind fcst error w/ TAMDAR assimilation

Aircraft reports below 20 Kft
TAMDAR only
including PenAir
12-23z 9 October 2008

TAMDAR
Observations
in Rapid Refresh



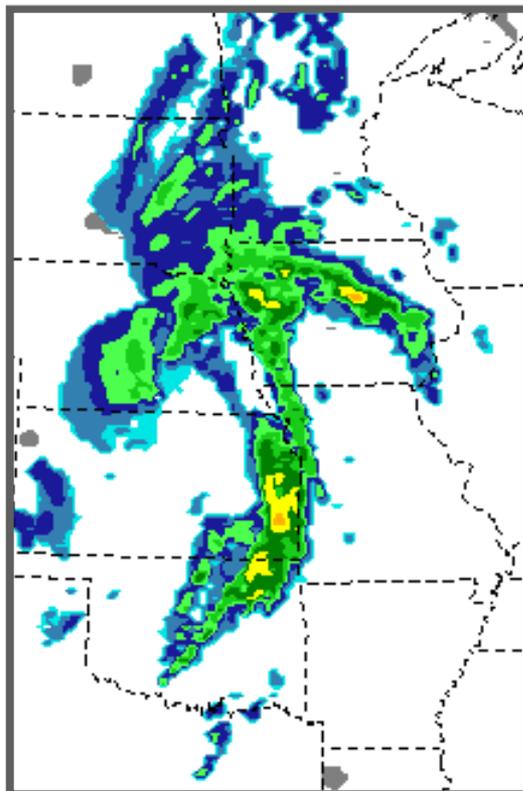
Radar data assimilation using Diabatic Digital Filter Initialization (DDFI) in WRF (v3.0), by ESRL/GSD and NCAR/MMM



Rapid Refresh (GSI + ARW)

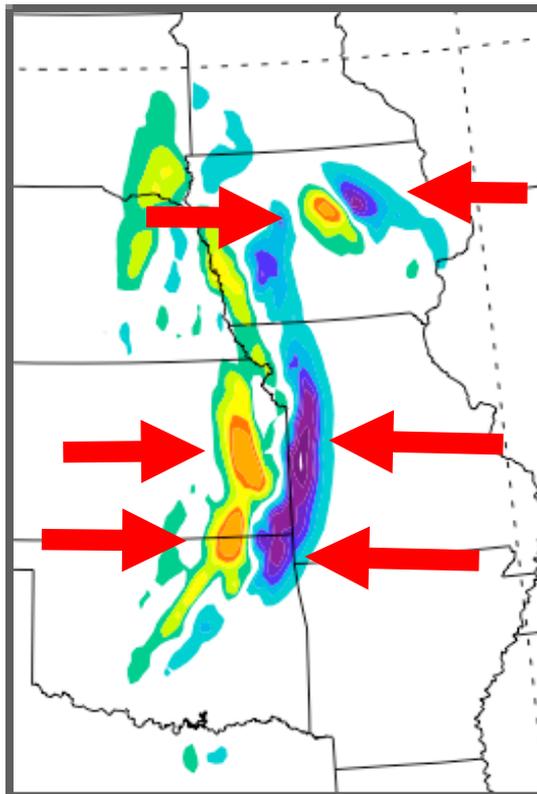
reflectivity assimilation example

NSSL radar
reflectivity (dBZ)



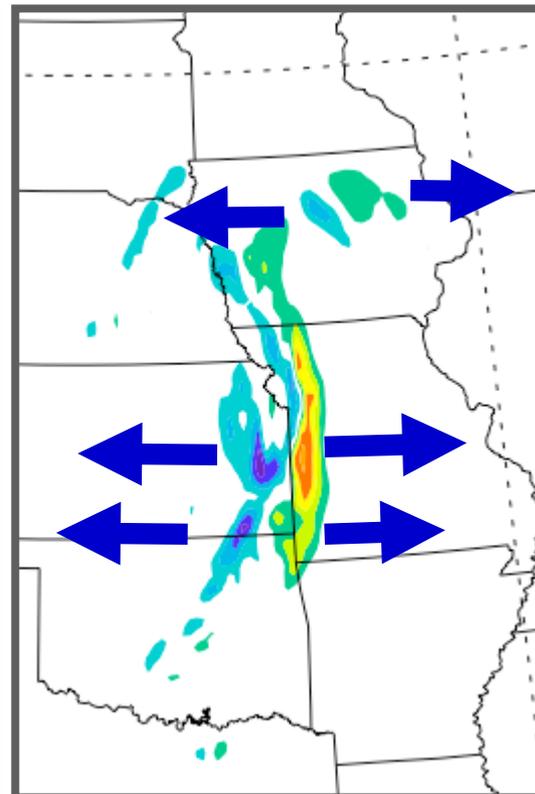
14z 22 Oct 2008
Z = 3 km

Low-level
Convergence

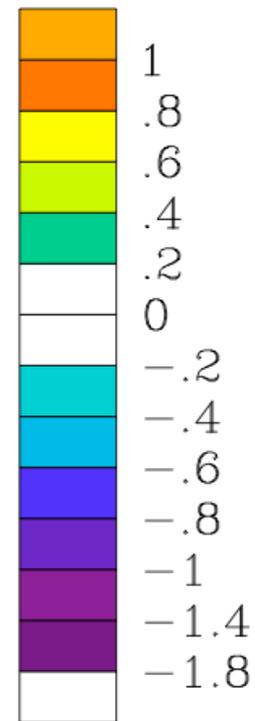


K=4 U-comp. diff
(radar - norad)

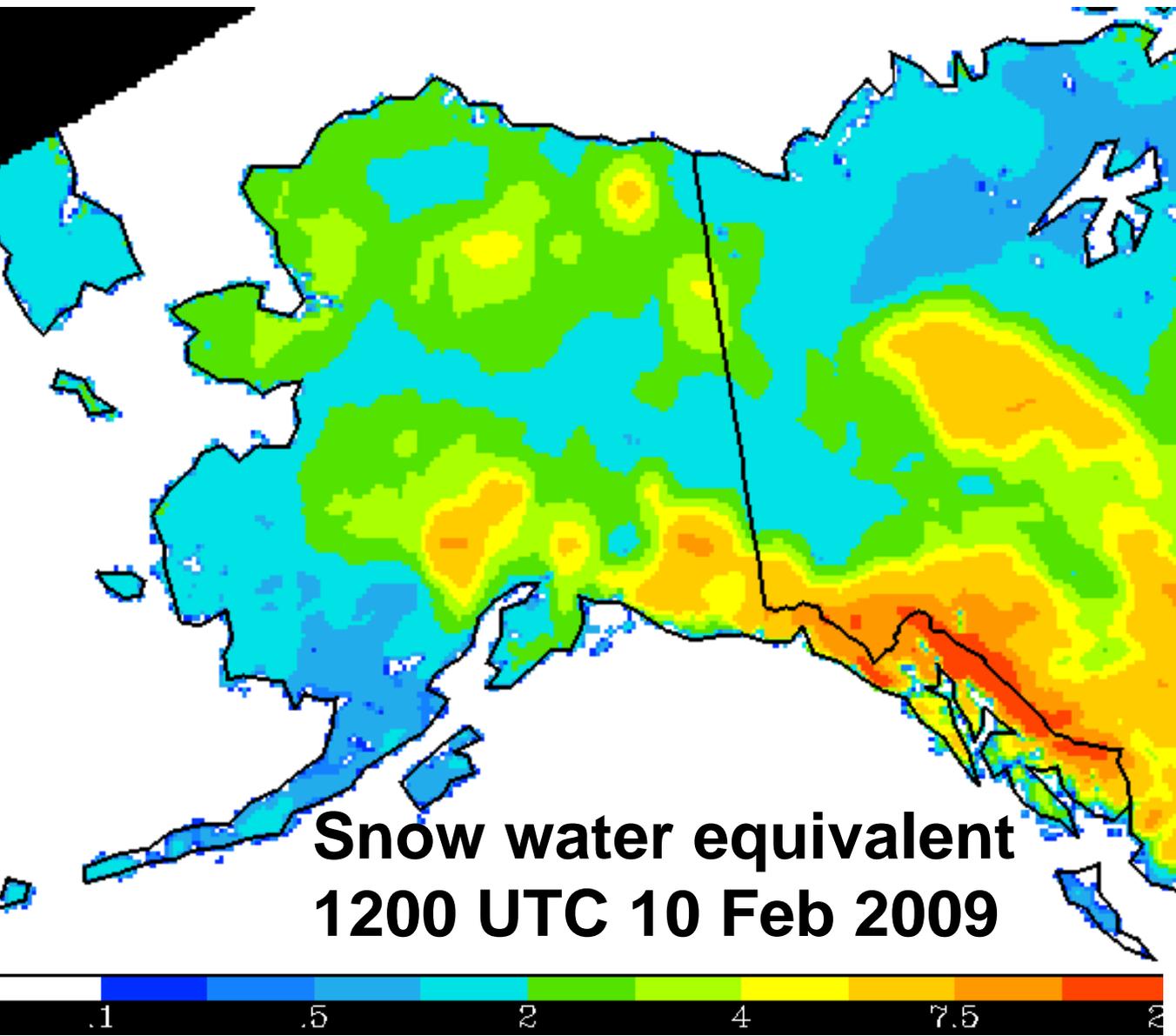
Upper-level
Divergence



K=17 U-comp. diff
(radar - norad)



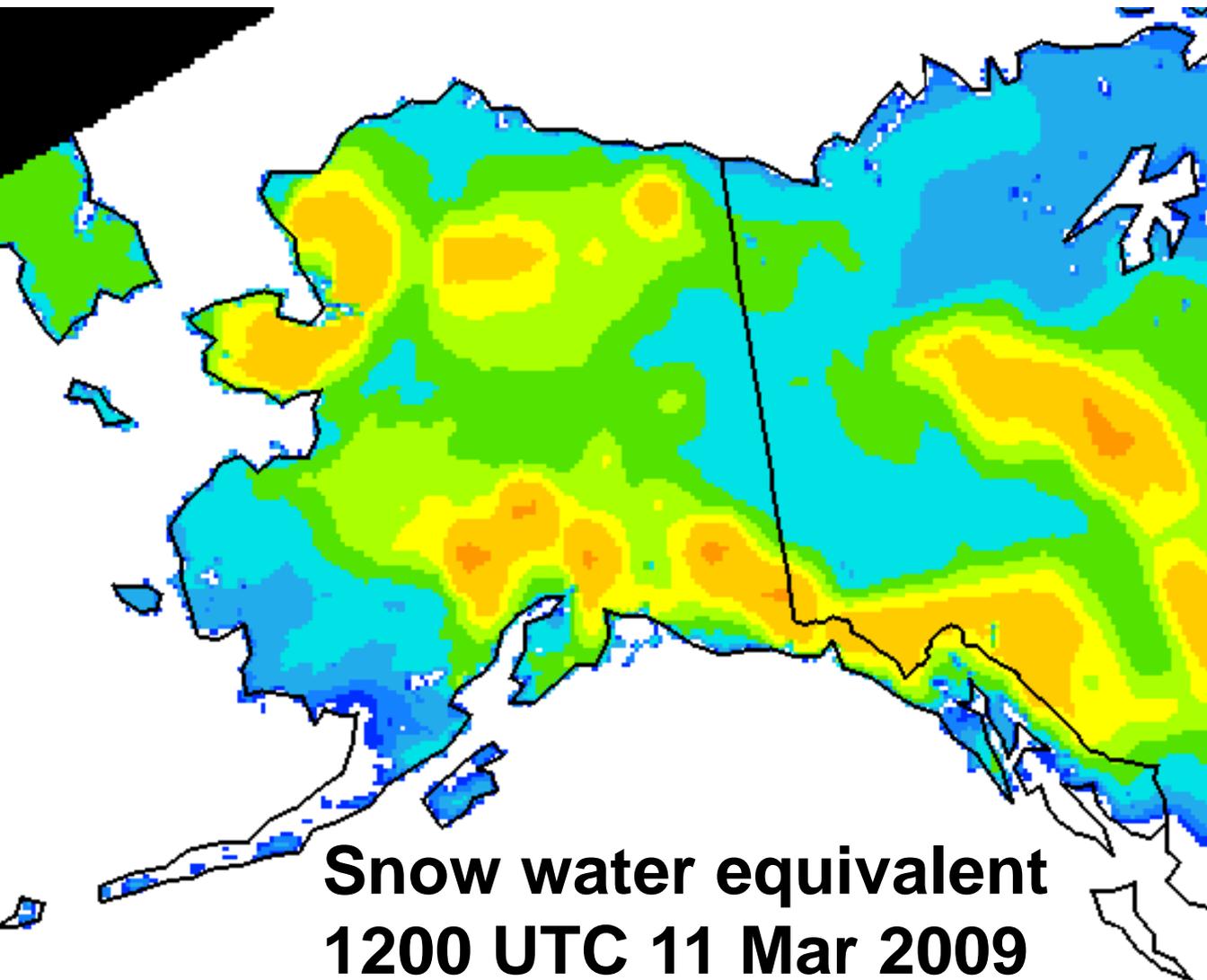
Unbroken cycle for RR LSM fields since ~ 8 Feb 2009



Previously,
fields resetting
to GFS (much
smoother) on
cold starts
(~every 3 days)

Fields cycled:
Soil temp
Soil moisture
Snow temp -lay 1
**Snow temp-lay 2
(added 3/11/09)**
Snow water
equivalent
Snow depth
Snow density

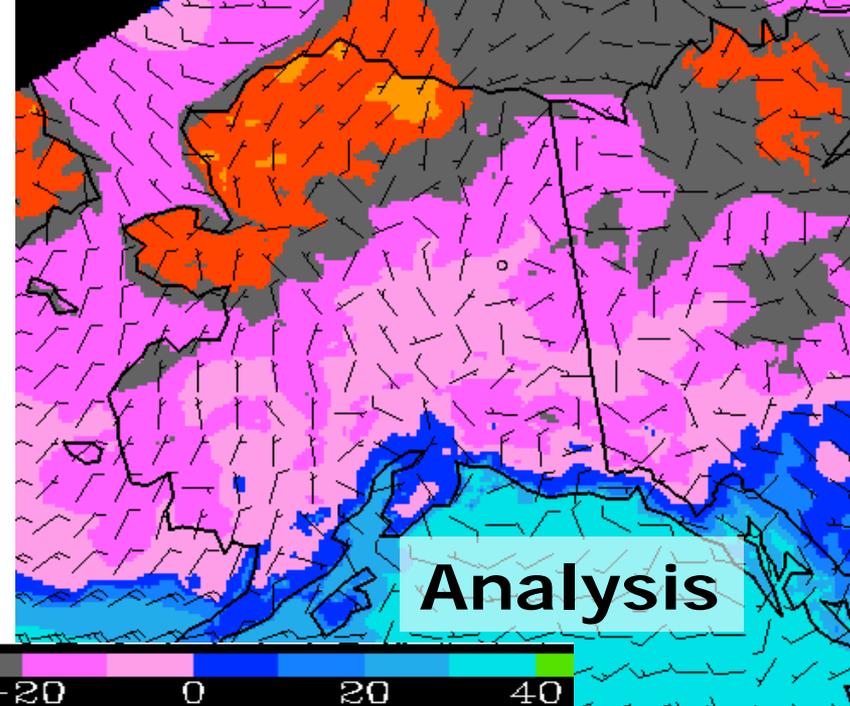
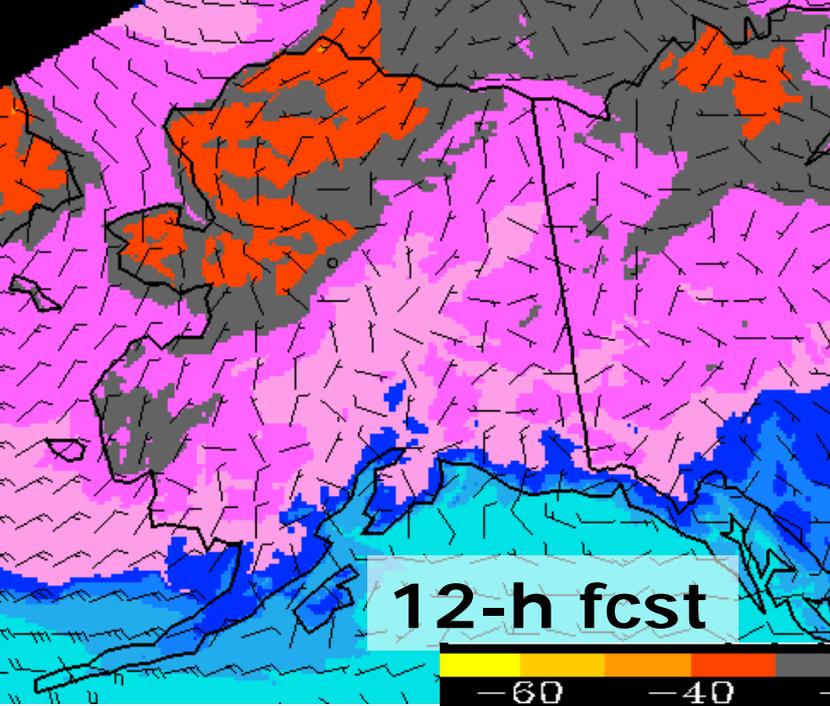
Unbroken cycle for RR LSM fields since ~ 8 Feb 2009



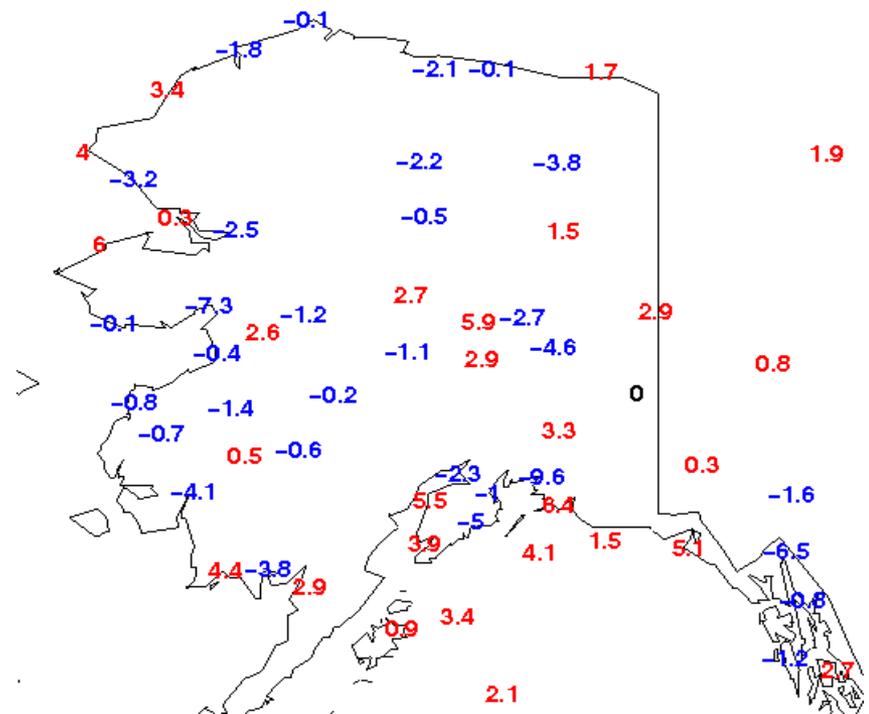
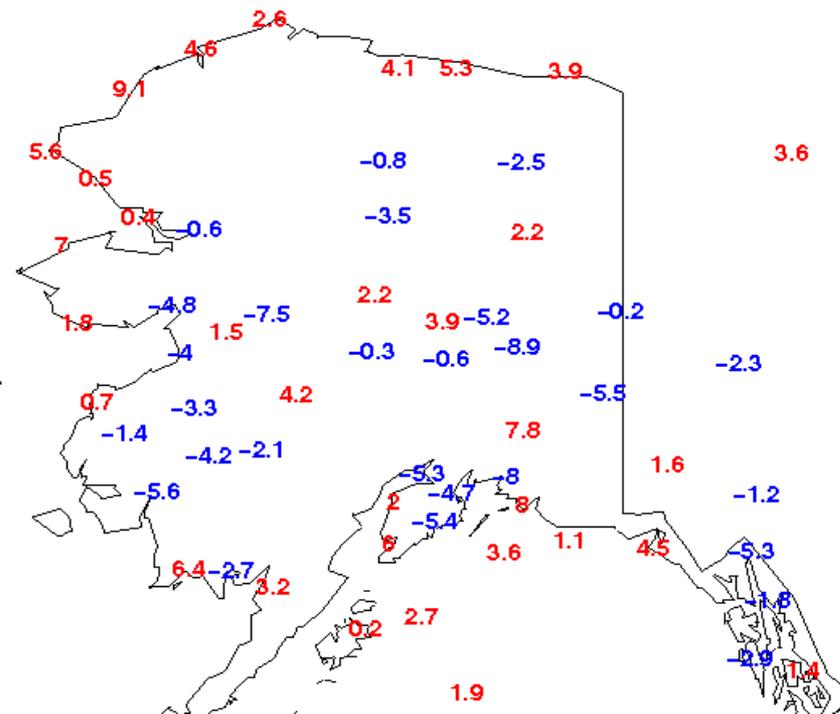
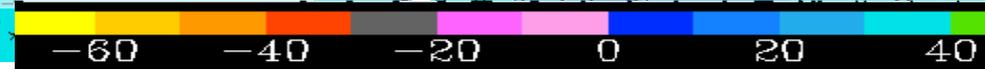
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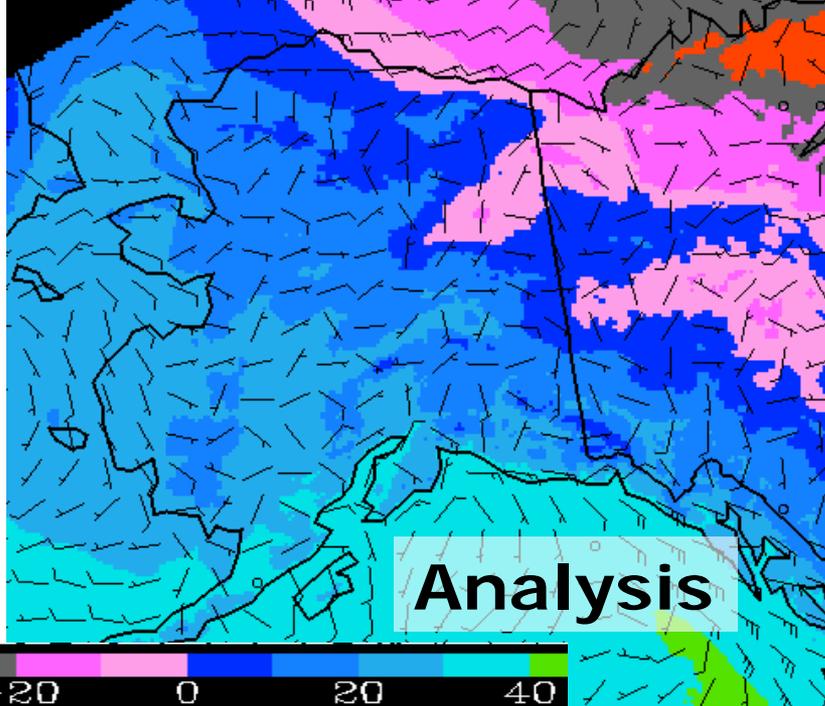
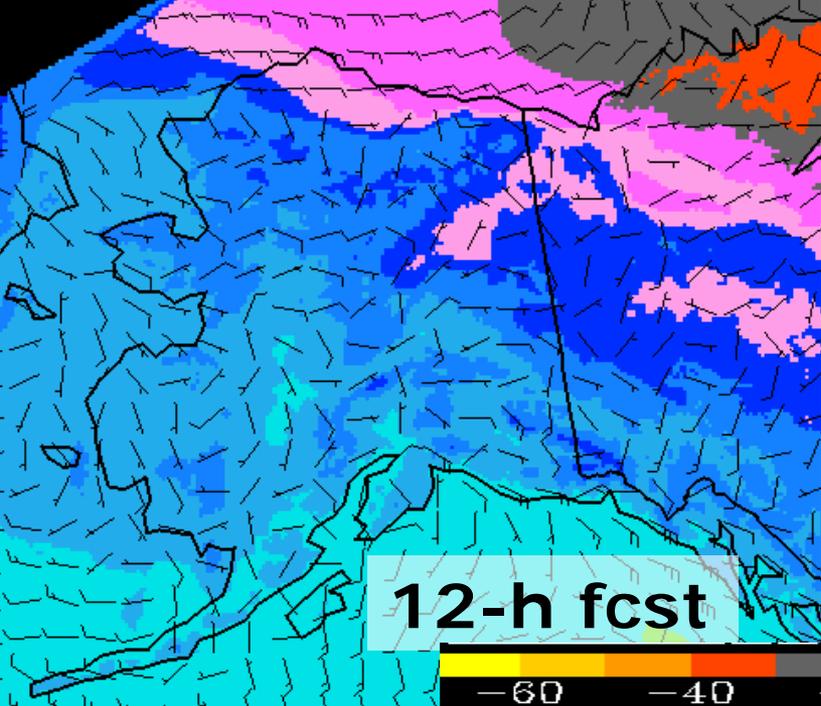
Fields cycled:
Soil temp
Soil moisture
Snow temp -lay 1
Snow temp -lay 2
(added 3/11/09)
Snow water
equivalent
Snow depth
Snow density

.1 .5 2 4 7.5 20



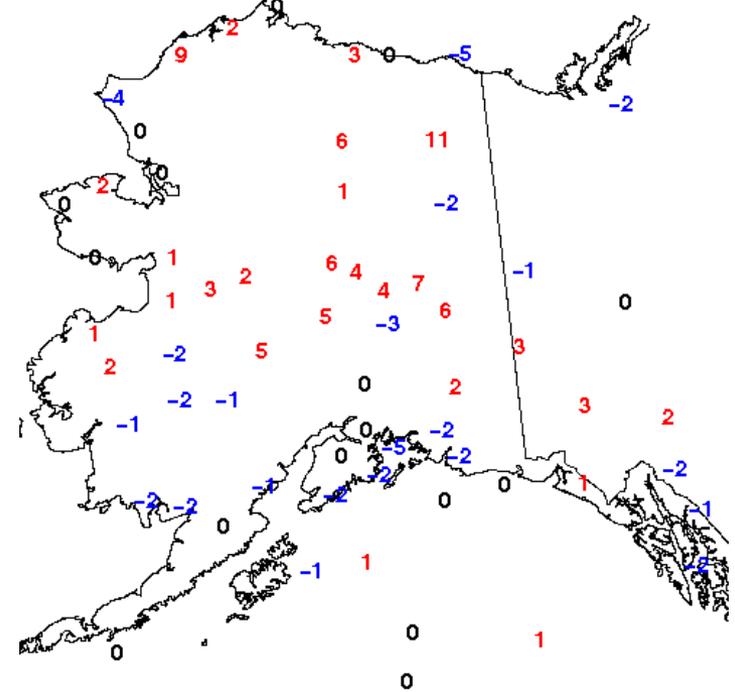
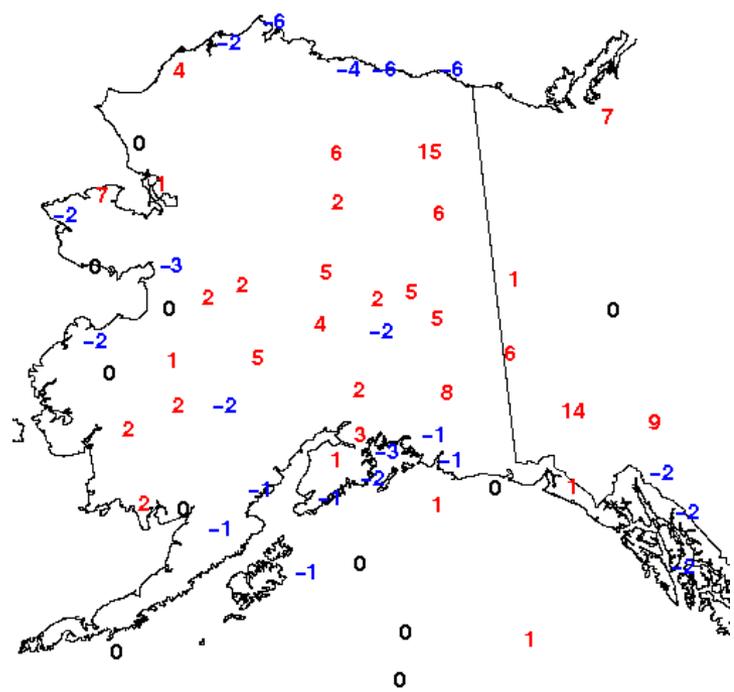
12z
9 Feb
Sfc
Temp





12z
11Mar

Sfc
Temp



2008 Evolution of RR Configuration

Comparison for 7-day retrospective period

Operational RUC

RR Jan. 2008

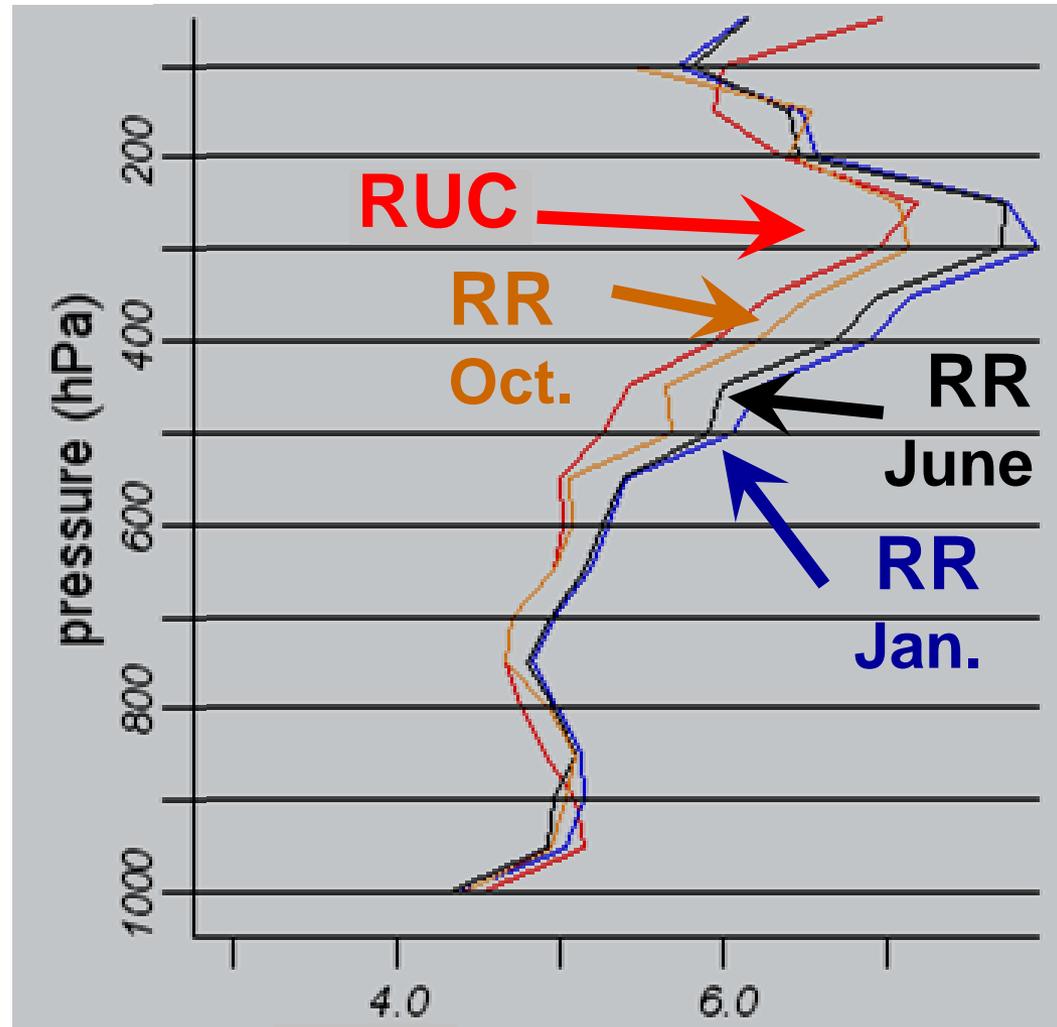
Global background
error covariance

RR June 2008

Regional background
error covariance

RR Oct. 2008

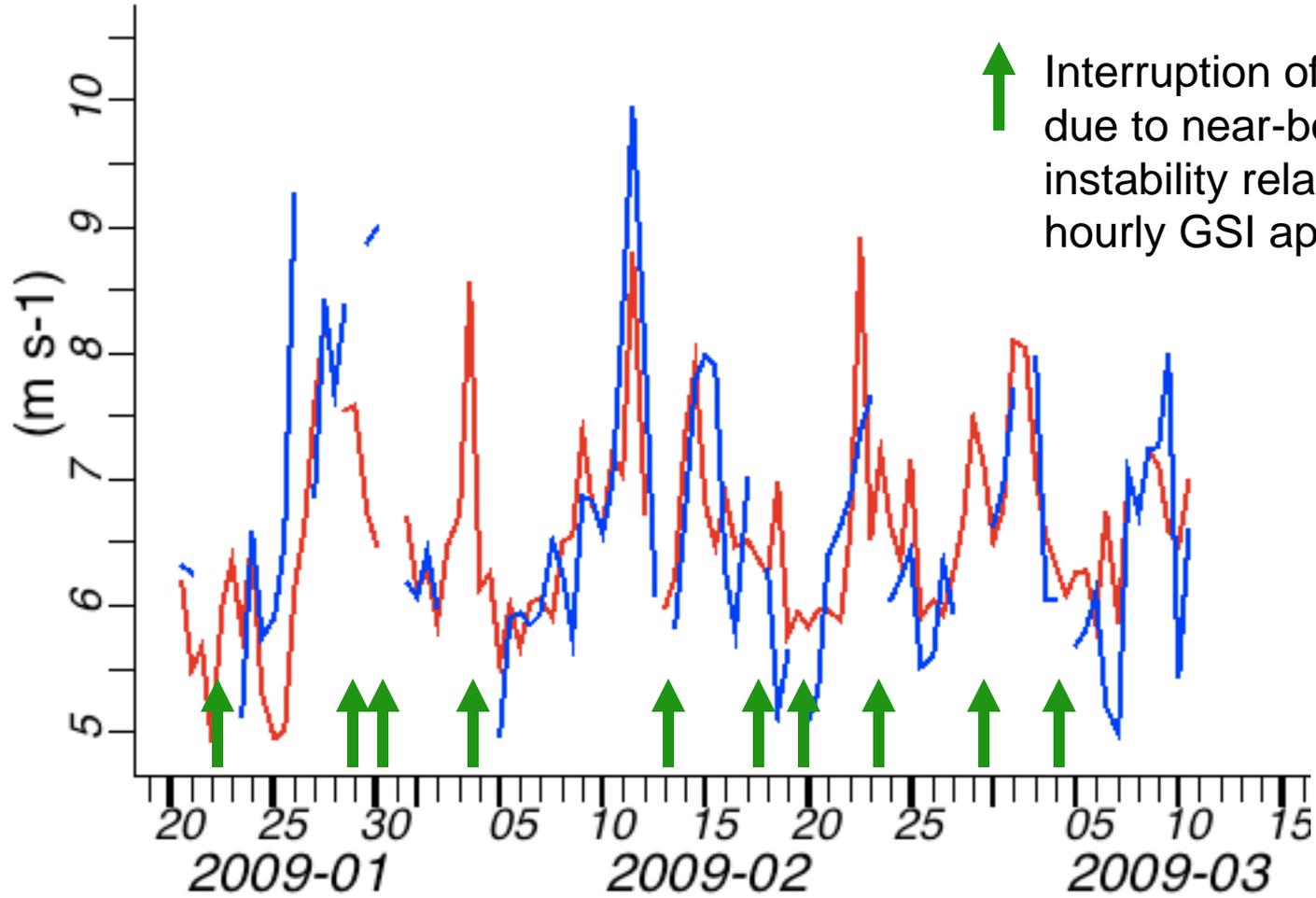
New regional GSI
WRFv3
DFI



Vertical profile - 12h fcst
vector wind RMS error (m/s)

12h wind forecasts, 300-200 hPa, RR vs. RUC

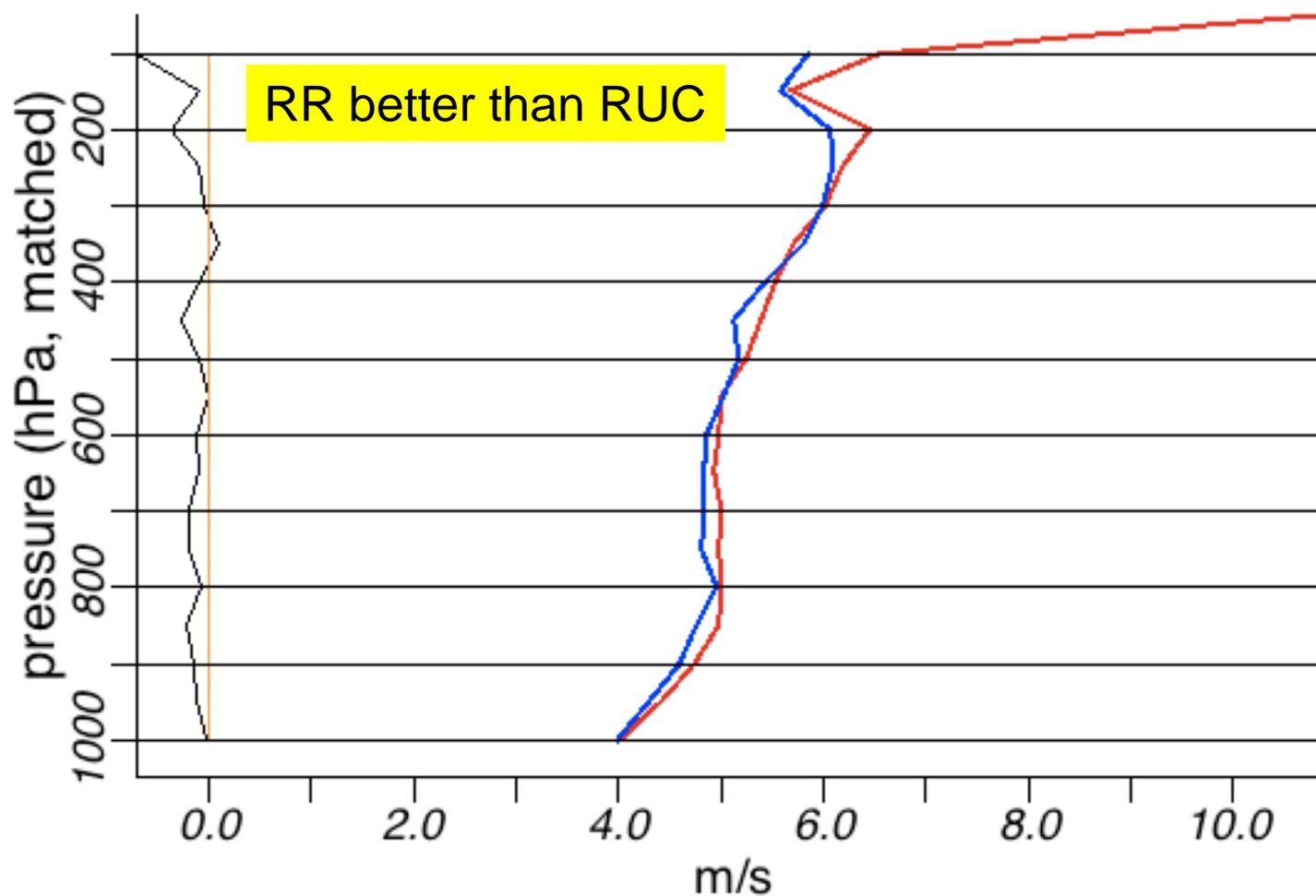
- RR1h rgn:RUC, 300-200mb winds rms 12h fcst
- Dev1320 rgn:RUC, 300-200mb winds rms 12h fcst



↑ Interruption of RR cycle due to near-boundary instability related to hourly GSI application

RUC (dev12) vs. RR - 12h wind forecasts 22 Feb - 10 Mar 2009

- RR1h-Dev1320 rgn:RUC, winds rms 12h fcst 2009-02-22 thru 2009-03-10
- RR1h rgn:RUC, winds rms 12h fcst 2009-02-22 thru 2009-03-10
- Dev1320 rgn:RUC, winds rms 12h fcst 2009-02-22 thru 2009-03-10



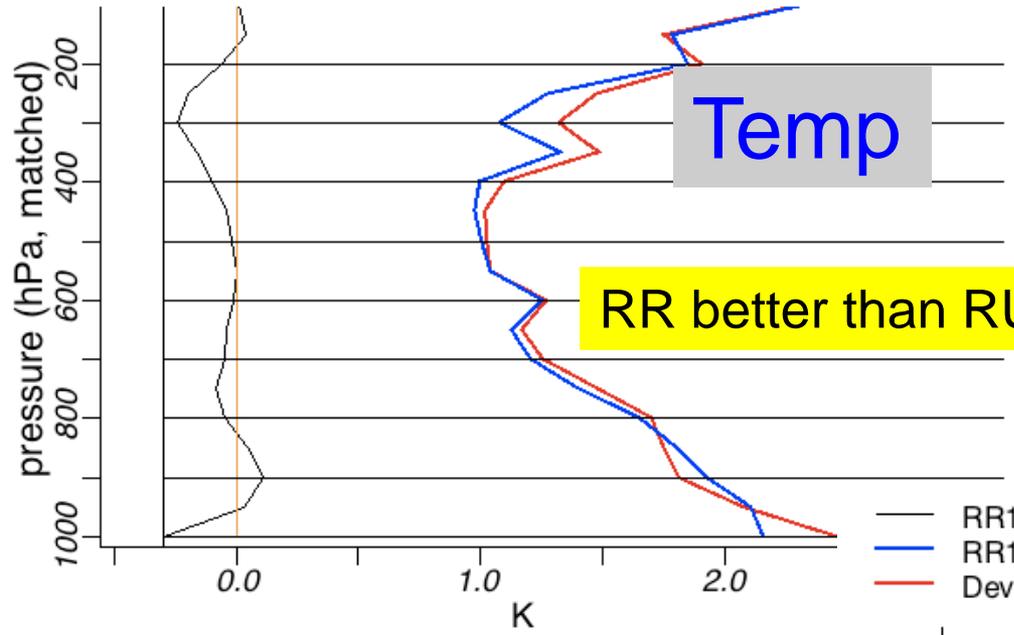
RUC (dev12)

vs.

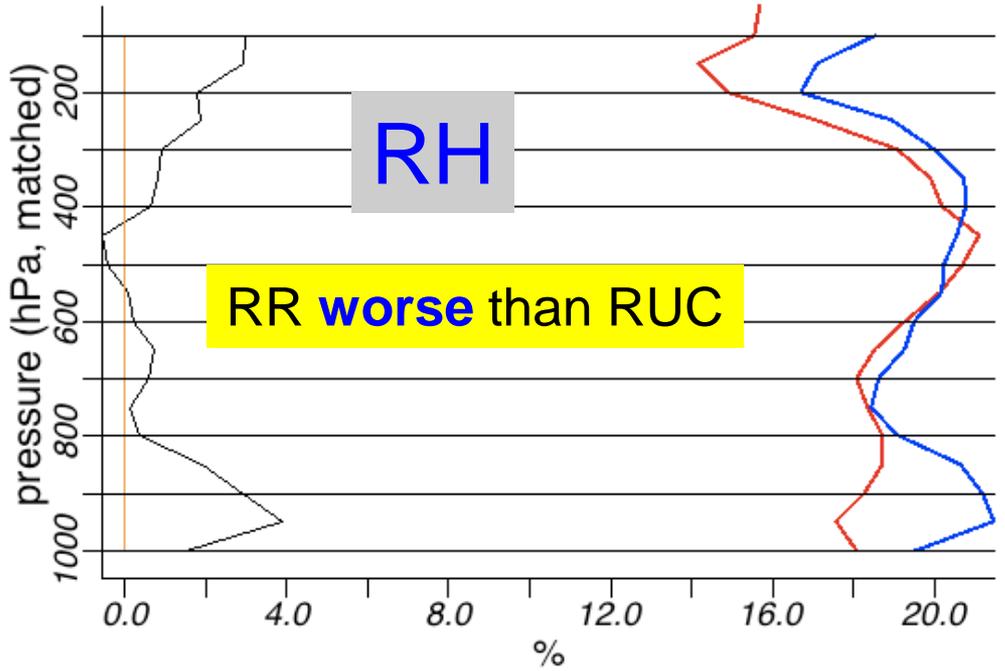
RR

2/22-3/10/09

- RR1h-Dev1320 rgn:RUC, temperature rms 12h fcst 2009-02-22 thru 2009-03-10
- RR1h rgn:RUC, temperature rms 12h fcst 2009-02-22 thru 2009-03-10
- Dev1320 rgn:RUC, temperature rms 12h fcst 2009-02-22 thru 2009-03-10



- RR1h-Dev1320 rgn:RUC, humidity rms 12h fcst 2009-02-22 thru 2009-03-10
- RR1h rgn:RUC, humidity rms 12h fcst 2009-02-22 thru 2009-03-10
- Dev1320 rgn:RUC, humidity rms 12h fcst 2009-02-22 thru 2009-03-10



Rapid Refresh – Summary

Current status (Mar 2009)

- Two parallel real-time hourly cycles at ESRL/GSD
- Ongoing evaluation & refinement, ftp grids to AK NWS
- Mid-phase evaluation - exceeding RUC for wind/temp

Remaining RR work at ESRL/GSD

- Shake-down cloud analysis, radar assimilation
- Refine error statistics for RR hourly cycle
- Complete special treatment for surface observations
- Complete modifications to WRFPost for RR fields

Tasks for NCEP implementation (planned 2010)

- Modify existing NCEP scripts to for 1-h cycling
- Real-time 1-h RR cycle experimental at NCEP
- Satisfy requirements (forecast skill, timing, etc.)
- Port code to NCO, final parallel tests, implement

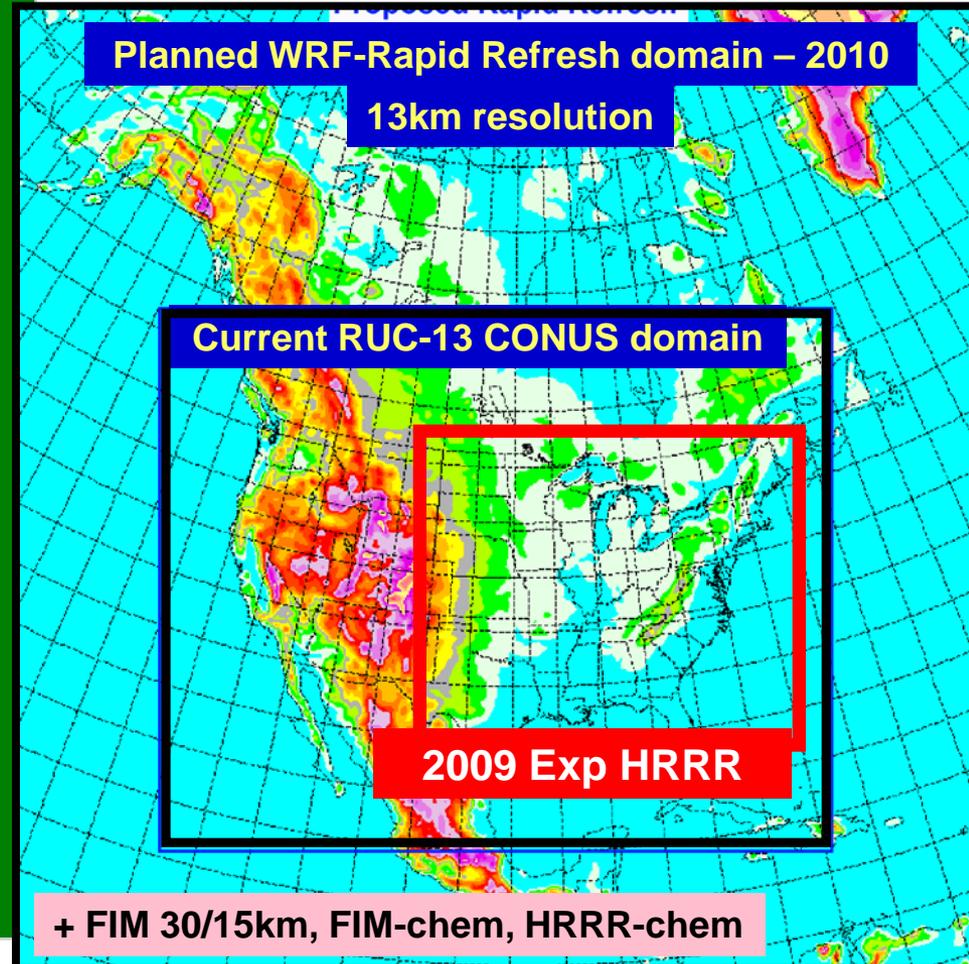
RR/HRRR Development and Testing

Major transitions:

- RUC13 change package – Nov 2008
 - radar reflectivity assimilation
 - TAMDAR
 - Improved radiation, convection physics in RUC
- RUC out to 18h hourly by 4Q FY09
- Rapid Refresh RFCed for ops by 2/10
 - WRF ARW, GSI, North America
 - implement by ~Jun 2010
- Ensemble Rapid Refresh
 - proposed by 2012
- High-Res Rapid Refresh (HRRR) – RR nest proposed to NCEP by 2012
 - 3km hourly updated 12h forecast incl. radar reflectivity assimilation
 - Demo testing at ESRL/GSD
- RR-chem, HRRR-chem, global-RR-~2016

<http://ruc.noaa.gov>

<http://rapidrefresh.noaa.gov>



Rapid Refresh

Purpose:

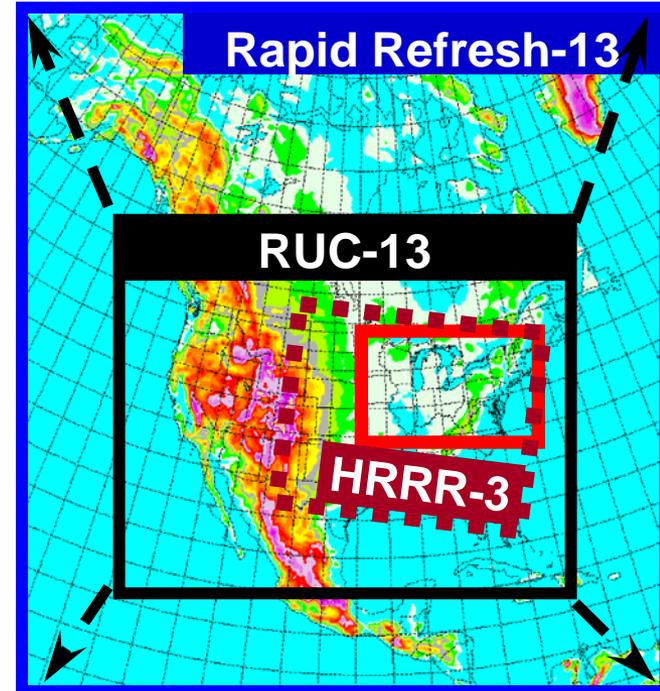
Evolutionary upgrade to NCEP operational RUC

- More advanced model and analysis package
- Retains aviation specific features from RUC (hourly cycle, cloud analysis, use of surface observations)
- **Consistent grids over all of NA for aviation hazards (convection, icing, turbulence, ceiling, visibility, etc.)**

Status:

RR system nearly mature, NCEP implement expected Q2-3 FY10

- 2 parallel R/T cycles at GSD
- Minor refinements ongoing
- Most performance metrics good
- RR grids to AWRP RTs, AK NWS
- NCEP transition effort underway

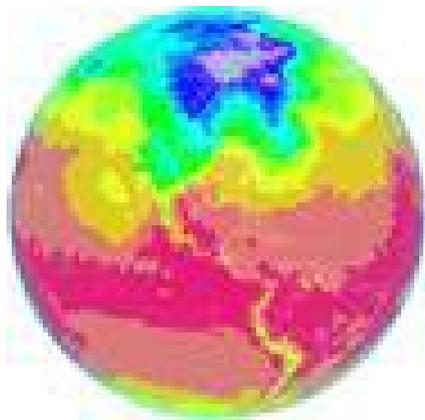


Rapid Refresh

RUC

HRRR

FIM



Real-time Rapid Refresh domain

Current RUC-13 CONUS domain

Experimental HRRR domain

